National Aeronautics and
Space Administration

The NASA Scientific Data Purchase Final Report

John C. Stennis Space Center, Mississippi

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Space Administration

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September 2003 DRAFT

Estimated 95% complete – M.E. Wise, 9/23/03

Acknowledgments

This work was supported by the NASA Earth Science Applications Directorate under contract number NAS 13-650 at the John C. Stennis Space Center, Mississippi.

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Foreward

In 1997, NASA initiated an innovative project called the Scientific Data Purchase (SDP). This experimental project resulted from a Congressional appropriation to investigate the utility of commercial remote sensing data for Earth science research. The project has now been completed and a summary of activities and relevance to NASA Earth science research and applications are presented here. This experimental SDP project has demonstrated that NASA can successfully implement a data purchase activity and that industry is willing to respond. In addition, the several examples included in this report indicate the utility of the commercial data and its impact to NASA Earth science research. This report is intended to provide useful information for government agencies considering future data purchases, including those civil agencies responsible for implementing the President's 2003 Commercial Remote Sensing Space Policy.

The goal of the SDP was designed to provide NASA's Earth science researchers with a commercial source of observations in addition to the suite of NASA-sponsored missions. As illustrated in the figure below, the spatial information cycle indicates the need for both public and private sources of Earth science observations and data products. In other words, researchers should be able to use data streams from both government missions *and* commercial systems to accomplish Earth science objectives. Therefore, an implicit objective of the SDP was to scientifically qualify a subset of commercially available products to meet specific needs of the Earth science community, products that were not available to them through NASA assets (e.g., high spatial resolution visible and near infrared imagery and Interferometric Synthetic Aperture Radar (IFSAR)). This effort has resulted in a process through which other sensors and Earth science products might become scientifically qualified in the future.

The relevance of the SDP and its results are reflected by its importance to NASA and U.S. Government sponsored research programs. For example, the U.S. Climate Change Science Program (CCSP) recognizes the importance of the "human dimension" in science research. To fully understand this concept, there will be requirements for observations of a certain applicable spatial resolution. In many cases, this requirement can only be satisfied with imagery from commercial high resolution sensors. Also, the Solid Earth Science Working Group (SESWG), in support of research in volcanoes, earthquakes, etc., has identified measuring subtle movements of the Earth's crust as early indicators of hazardous events such as land slides, earthquakes and volcanoes. Many of the observations for this community require high spatial and temporal resolution LIDAR and IFSAR technologies. At present, the commercial industry is the primary source for these types of data from aircraft. Other Federal research programs (e.g., U.S. Weather Research Program, Climate Change Technology Program) are also candidates for the use of commercially available scientifically qualified Earth science products. Ultimately, the results of the SDP could potentially have far-reaching effects on how the U.S. Government conducts its Earth system science research in the future.

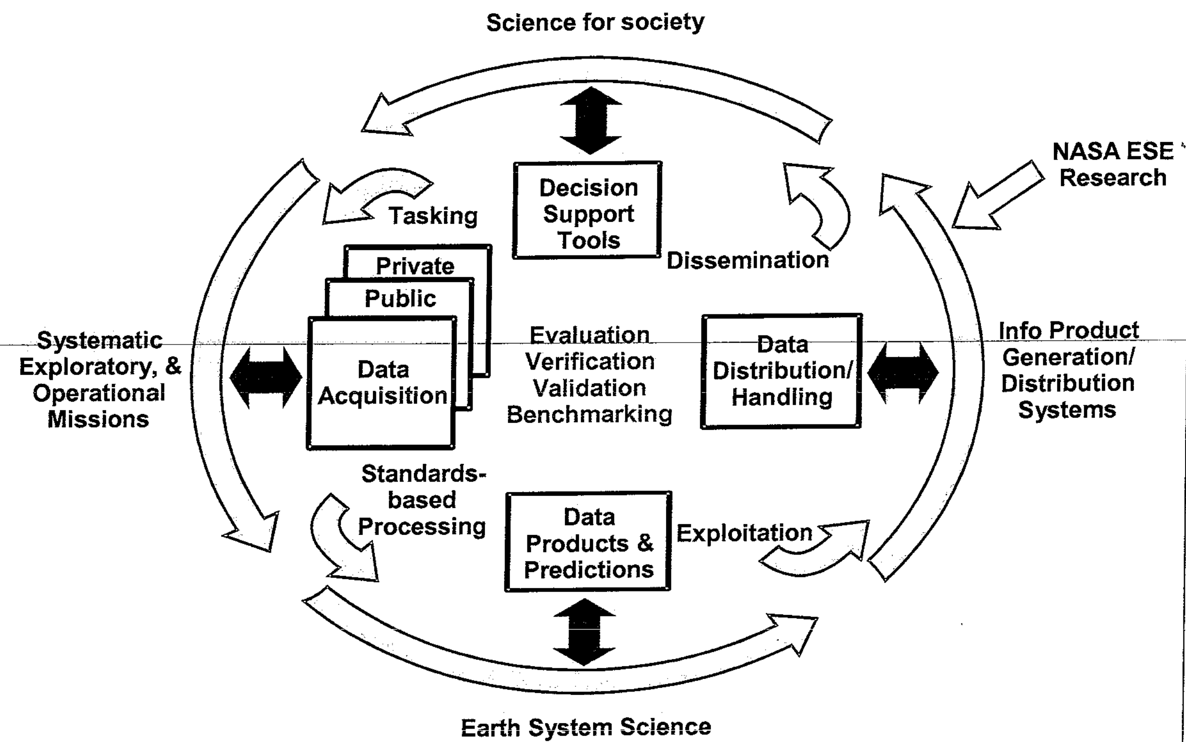


Figure 1. Spatial information cycle.

Executive Summary

This report summarizes the results of the NASA Scientific Data Purchase (SDP) program implemented by the Stennis Space Center Earth Science Application Directorate in fiscal years 1998-2002.

The SDP was conducted in support of NASA's Mission to Planet Earth (MTPE) program (currently known as NASA's Earth Science Enterprise). This Earth Science Enterprise (ESE) provides major observational capabilities for NASA's Earth system science research and the U.S. Global Change Research Program. Observations supported through the SDP were selected based upon their application to the five science themes of the MTPE/ESE:

- Land-cover and land-use change research
- Seasonal-to-interannual climate variability and prediction
- Natural hazards research and applications
- Long-term climate: Natural variability and change research
- Atmospheric ozone research

The MTPE/ESE science themes, although they have evolved over time, are driven by a set of key science questions that help focus the research program on characterizing the Earth system. More details on these questions may be obtained by reading the MTPE/ESE Science Research Plan. Use correct document title, and insert reference.

The NASA Scientific Data Purchase program began in 1997 as the result of a $50 million Congressional appropriation intended to establish a series of demonstration projects for evaluating the utility of commercial remote sensing data (National Research Council, 2002). The goals of the program were to assess the use of commercially available remote sensing data for scientific purposes and to gage the willingness of industry to accept a major portion of the up-front financial responsibility associated with routinely providing remotely sensed data products in a cost-effective and timely manner (Appendix A). NASA developed a two-phased approach for the implementation of the Scientific Data Purchase program. This two-phased approach made it possible to evaluate the science value of proposed data (Phase I) before committing to additional multi-year data purchases later (Phase II), thus minimizing the risk to the government. In September 1998, NASA selected five commercial vendors to provide high quality remotely sensed data products to a broad segment of the NASA Earth science community. NASA Stennis Space Center (SSC) was assigned the management responsibility for implementing the SDP.

The SDP demonstrated that the commercial remote sensing industry, although still maturing, could provide the Earth science community with some unique, useful, and valuable products. These products included a variety of data types generally not available to NASA Earth science researchers: very high spatial resolution IKONOS satellite imagery acquired from Space Imaging, LLC.; airborne multispectral imagery from Positive Systems, Inc.; high-accuracy digital elevation model and radar imagery from DigitalGlobe (then EarthWatch, Inc.) through Intermap Technologies, Inc. STAR-3*i* Interferometric Synthetic Aperture Radar; and the first-ever global database of orthorectified Landsat imagery from Earth Satellite Corporation (EarthSat). A summary of these data products is listed in Table B-1. The remaining SDP vendor, AstroVision, Inc., was selected to provide full-disk images of the Earth for global monitoring and natural hazards event viewing upon the launch of its geostationary-orbiting system in the future. Unfortunately, AstroVision was not able to develop and launch their system prior to the end of their SDP contract, and this contract was subsequently canceled.

NASA Earth science researchers requested SDP data by submitting tasking requests via the SDP website (http://www.esad.ssc.nasa.gov/datapurchase/). The requests, similar to research proposals, included a detailed description of how SDP data would be used to support ongoing NASA Earth science research and applications. A NASA Headquarters tasking review committee ensured that SDP data was used to support a wide variety of science research and application areas. The largest portions of data requested through task requests were in support of land cover/land use studies, Earth Observing System (EOS) science validation, and resource management applications. Commercial data acquired through the SDP has greatly benefited several NASA research and applications projects. These projects span a variety of NASA-sponsored research and applications studies. A few of the high-impact results include the following:

- Researchers at the University of South Carolina demonstrated how EarthSat GeoCover Landsat orthorectified data could be used to support the U.S. Government Geographic Information for Sustainable Development initiatives through coastal management studies in Tanzania/Kenya. The results of this study were incorporated into a National Academy of Sciences report (Jensen et al., 2002) that was presented at the World Summit on Sustainable Development in September 2002, citing the significance of the EarthSat dataset as the only relatively high spatial resolution global orthorectified dataset available to most developing countries for use in sustainable development projects.
- Space Imaging's IKONOS imagery was used to support studies of sensitive island landscapes and quantifying their responses to changing global conditions, including coastline change, volcanic effects, island subsidence and sea level effects, and effects of ice accumulations. IKONOS imagery provided a mechanism to develop response models that can be extended to more complex regions. An exciting outcome of these studies has been the use of the high spatial resolution imagery as "training" data for remote sensing observations and prospective studies of Mars. The use of SDP high resolution imagery has influenced NASA's decision to implement a sub-meter imaging system on the Mars Reconnaissance Orbiter, which is scheduled for launch in 2005.
- NASA Langley Research Center scientists used DigitalGlobe/Intermap Star-3*i* digital elevation data and Space Imaging IKONOS imagery to support improved aviation safety in Alaska. The SDP data, combined with aircraft attitude and position information, were used to generate Synthetic Vision System cockpit displays - accurate heads-down views of the mountainous Alaska terrain. These 3-D simulated window views of the terrain demonstrate how remotely sensed imagery can be used to improve pilot situational awareness during poor visibility conditions.
- The Moderate Resolution Imaging Spectrometer (MODIS) Land Validation Team employed Space Imaging's IKONOS imagery for validation of MODIS land products. The high-resolution spaceborne imagery served several purposes, including co-registration of other remotely sensed data, design of field sampling strategies, investigation of Landsat 7 Enhanced Thematic Mapper Plus sub-pixel heterogeneities, and spatial variability studies.

Through NASA's SDP, affiliated research scientists have produced 291 publications, including peer-reviewed journal articles, conference presentations and web articles. To date, of the studies described in these publications, 30 utilized EarthSat data, 20 utilized EarthWatch data, 32 utilized Positive Systems data, and 209 have utilized Space Imaging data. A list of these cited references is provided in Appendix D. Issues regarding the amount of time it took to receive the SDP data (the time from data acquisition to data receipt) and data rights restrictions were the main problems expressed by small percentage of the SDP researchers.

The SDP has resulted in several lessons learned. Several of the most significant include:

- NASA, with limited risk, can procure commercial data that is useful to Earth Science Enterprise affiliated research scientists, and industry is willing to accept the up-front financial responsibility associated with a data purchase program, where commercial markets exists beyond NASA requirements.
- NASA has gained an increased understanding of the maturing remote sensing industry and of how the industry and government should approach the many complex issues surrounding commercial imagery purchases (National Research Council report, 2002).
- Proper independent characterization of commercial data is essential for the science community, and is important to the applications community. Partnerships with other agencies can contribute to the success of government characterization efforts.
- The centralization of SDP contract, tasking, and data management activities in one location (Stennis Space Center) increased the efficiency of the SDP program and contributed to the effectiveness of verification and validation activities.
- Issues related to export control, data licensing, data archiving, and contract definition are all critical to successful data purchase partnerships and must be addressed at the earliest steps of negotiation.

The SDP has been described as a valuable model, among only a few in the U.S. government, for making commercial data products available to government users (National Research Council, 2002). However, several challenges must be addressed to ensure the success of future programs.. Data licensing agreements that better serve the needs of long-term research are essential. Additionally, a survey of commercial data offerings combined with a systematic study of NASA's Earth science data needs would be beneficial for future programs. NASA's Suborbital Program is currently planning to work with the private sector to understand commercial offerings, and to discuss approaches to scientifically qualify commercial assets for NASA research use.

This report was written by SSC's ESA Directorate in support of NASA's Earth Science Enterprise. The ESA Directorate has a history of working with other government agencies, academia, and the private sector to advance remote sensing applications and products and has developed a series of unique public-private partnerships. Over the years, the ESA Directorate has partnered with several operational agencies, colleges and universities, and commercial data providers to collaborate on the development of new products and services that incorporate NASA science and technology results.

The following report includes a background and description of the Scientific Data Purchase Program and its processes, a description of several research activities impacted by SDP data, and a summary of lessons learned during the SDP Program. Additional detailed information is also provided in the appendices. A more thorough, independent review of the SDP program is recommended and should include an assessment of science value and relationship to current NASA Earth science and applications themes, an analysis of existing and planned private sector capabilities, and an evaluation of the effectiveness of SDP management processes.

1.0 Introduction

The NASA Scientific Data Purchase (SDP) program tested the utility and expanded the use of commercial remote sensing data by the NASA Earth science community. Through the SDP, NASA's Mission to Planet Earth (MTPE) tested a new way of doing business by acquiring remote sensing data products from contracted commercial data providers. In 1998, NASA's MTPE was renamed Earth Science Enterprise (ESE) to reflect the direction of NASA's research into the emerging discipline of Earth system science. (For clarity, since the transition has been made, the rest of this document will refer to ESE, not MTPE.) NASA scientists used the commercial data to support ongoing Earth science and applications research.

This document provides: 1) an evaluation of the overall effectiveness of the SDP program (to date) and the utility of commercial remote sensing data for Earth science research and applications, 2) a summary of the SDP implementation and lessons learned, and 3) a resource for future government data purchase planning and implementation activities.

2.0 SDP Background

The SDP resulted from a 1997 Congressional mandate directing NASA to allocate $50 million for the purchase of remotely sensed data from commercial sources that could meet NASA's science requirements (U.S. Senate, 1996). This mandate stated specifically that NASA should purchase commercial data "where feasible and cost-effective," if these data sources "fully satisfy the scientific requirements of NASA."

Aware of the impending Congressional directive, NASA researched the available and planned commercial industry data products through the release of a Request for Information (RFI) in May 1996. The purpose of the RFI was to determine if the commercial sector could supply Earth observation data suitable to support NASA's basic and applied research in Earth System Science. The RFI also explored the willingness of industry to accept a major portion of the upfront financial responsibility in system development as a new way of doing business with the government. The RFI requested information from commercial entities on data sources to support the current Earth Science Enterprise (ESE) science research theme areas. Using the information provided by the RFI, NASA developed a two-phased approach for the implementation of the Scientific Data Purchase program. A two-phased approach made it possible to evaluate the critical characteristics and value of proposed data (Phase I) before actually committing to additional specific data purchases (Phase II), thus minimizing the risk to the government.

On May 23, 1997, NASA Request for Offer RFO No.13-SSC-O-97-21 (provided in Appendix A) solicited proposals for Phase I of the Earth Science Enterprise Scientific Data Purchase program. The RFO called for remotely sensed datasets that would provide new science measurements and/or more cost-effective ways of performing ESE research. Respondents were asked to provide information on data products, price, data validation, data licensing, and applicability to the then current ESE (MTPE) science research themes:

1. Land-Cover and Land-Use Change Research

2. Seasonal-to-Interannual Climate Variability and Prediction

3. Natural Hazards Research and Applications

4. Long-Term Climate: Natural Variability and Change Research

5. Atmospheric Ozone Research

The release of the RFO and management and responsibility for implementing the SDP program was assigned to NASA's Earth Science Applications (ESA) Directorate (then known as the Commercial Remote Sensing Program) at Stennis Space Center (SSC).

Eighteen companies submitted Phase I proposals offering sixty-five different prototypical products consisting of both actual and simulated data. The proposals covered a wide variety of sensor types, data types, resolutions, physical parameters, and processing levels. Phase I proposals were evaluated by both science and business teams. Evaluation criteria included best value characteristics such as business and pricing factors, science relevance, and past performance (Appendix A). In December 1997, 10 contracts were awarded for twenty-two Phase I products.

2.1 Phase I Activities

During Phase I, the ten contractors acquired, developed, or simulated prototypical datasets and delivered them to NASA. A total of $3.9 Million was allocated to Phase I contracts and support activities. The goal of Phase I was to evaluate the prototypical datasets to select products for purchase and use in Phase II of the SDP. Selection of datasets for Phase II was based on an assessment of scientific value, technical risk, and business risk. An independent science assessment was conducted to determine the scientific value for each Phase I data product. Under the oversight of ESE Science Theme Managers, five science teams (representing each theme area) composed of academic and government research scientists were assembled. Early in Phase I, the Science Assessment Teams formed working groups pertaining to their area of expertise and established metrics, viewed data samples, reviewed proposals, discussed data distribution and data licensing, examined science needs, and evaluated Phase I products. The scientists assessed each data product separately, considering contribution to science themes, global change research, and ESE goals.

Engineers and scientists in the ESA Directorate at SSC conducted independent verification and validation (V&V) of the Phase I data. The objective was to provide the Phase I Science Assessment Teams with information on data quality based on an independent review. Verification included a check of key data specifications such as cloud cover, frame overlap, and metadata to ensure that the terms of the Phase I contract were fulfilled. To support the science assessment, information on the full product-generation process was collected, including documentation on the sensor, the mission, ground instruments, data collection methods, image processing, references, and company test results. Phase I validation of system performance included a review of laboratory calibration reports and an analysis of operational performance on spatial, spectral, geopositional, and radiometric accuracies. Image products were validated for vertical and horizontal coordinate accuracy and for classification accuracy. In some cases, simulation or production algorithms were also examined.

The Science Assessment Teams reviewed the results of SSC data validation, heard presentations from the data vendors, examined aspects of the data, and formed a consensus on Phase II science recommendations. The teams provided recommendations to NASA regarding data purchase conditions, limitations, concerns, enhancements, geographic coverage, revisit times, and prioritization (Goward et al., 1998).

The Science Assessment Teams' recommendations, along with technical and business risk, were assessed, and Phase II award recommendations were presented to the NASA ESE Associate Administrator, who served as selecting official. At the close of fiscal year 1998, five companies were awarded Phase II data purchase contracts: AstroVision International, Inc., Earth Satellite Corporation, EarthWatch, Inc., Positive Systems, Inc., and Space Imaging, LLC.

2.2 Phase II Activities

The objective of Phase II of the SDP was to provide data to NASA's affiliated researchers to support ongoing Earth science research and applications. Four Phase II data providers were awarded three-year indefinite delivery indefinite quantity (IDIQ) contracts beginning in September 1998; one data provider was awarded a firm-fixed-price contract for a fixed number of products. The IDIQ contract mechanism allowed NASA to purchase a minimum amount of data from each provider, with the option of purchasing additional data, up to a maximum amount. This allows data to be purchased as needed through task orders issued to the contractor. During Phase II, approximately 7.5 terabytes of distributable data were purchased from four of the five data provider companies. A summary of products purchased during Phase II is shown in **Table 1**.

Stennis Space Center's ESA Directorate administered the Phase II contracts. SDP Phase II administration includes processing of science data requests, interaction with the Phase II companies, delivery verification, data characterization, and data distribution. $4.2 million was allocated to the SDP administration and independent data characterization activities.

2.2.1 Products and Licensing

2.2.1.1 Earth Satellite Corporation

The Earth Satellite Corporation (EarthSat), located in Rockville, Maryland, was awarded a $16.4 million contract to deliver orthorectified Landsat imagery covering global land areas for two historical time frames. The first, Multispectral Scanner (MSS) imagery collected during the mid-1970s, contains some of the earliest images of Earth taken from space. The second is Thematic Mapper (TM) imagery collected during the late-1980s and early 1990s. Both datasets were intended to serve as a baseline for studies of global change. EarthSat achieved global coverage by acquiring historical imagery from U.S. archives and foreign ground stations. The best available scenes for each Landsat path/row were selected through collaborative evaluation with scientists at NASA's Goddard Space Flight Center. The TM and MSS imagery were orthorectified to an accuracy of ±50 meters root mean square error (RMSE) and ±100 meters RMSE, respectively, using control points from government sources. The company also provided mosaic scenes of the TM coverage.

Science rationale for Phase II purchase of EarthSat products included the following: "A common universal geographic reference framework for Landsat imagery is needed for providing spatial data and image information, since none exists at present. The proposed orthorectified image data set will be the only universally available global data set, unencumbered by licenses or user restrictions" (Goward et al., 1998).

2.2.1.2 Digital Globe, Inc.

Digital Globe (then known as EarthWatch, Inc.) of Longmont, Colorado, in partnership with Intermap Technologies, Inc., was awarded a $6.2 million SDP Phase II contract to provide radar and elevation data from an airborne Interferometric Synthetic Aperture Radar (IFSAR) system. The STAR-3*i* X-band radar imagery was collected at 2.5-meter resolution and processed into 7.5' quadrangle mosaics. Orthorectified radar image maps have a horizontal accuracy of ±2.5 meters RMSE. Digital elevation model (DEM) products have a horizontal accuracy of ±2.5 meters RMSE and a vertical accuracy ranging from ±1 meter to ±3 meters RMSE. The data is useful for a wide range of applications involving land use, land cover, and terrain modeling.

Phase II science assessment rationale for selection of the Star3i products included the following comments: "There is a need on a regional basis for 3-meter interferometric X-band SAR data with co-registered 2.5-meter DEM data at a z-accuracy of <3 meters for both regional land use/land cover assessment and hydrologic modeling research. The X-band SAR data are of significant value for obtaining information on canopy surface characteristics, wetlands distribution, and detailed urban structure, especially in cloud-shrouded environments Optical photogrammetry can provide more accurate DEMs, but not in perennially cloudy areas. Data may also be of significant value during cloud-shrouded disasters" (Goward et al., 1998).

2.2.1.3 Positive Systems, Inc.

A $2.9 million contract was awarded to Positive Systems, Inc., of Whitefish, Montana, to provide 1-meter multispectral imagery, image mosaics, and collateral ground truth data. The imagery was captured with the Airborne Data Acquisition and Registration (ADAR) 5500, an 8-bit sensor with bands similar to the first four Landsat bands. The sensor is capable of producing imagery and mosaics referenced to 1:24,000 scale national map accuracy standards. In addition to providing high-resolution detail on land use and land cover, Positive Systems datasets and products are useful for ground calibration and cross-sensor comparisons.

Comments from the Phase II science assessment team provided the rationale for the Phase II purchase of ADAR5500 data. Comments included: "Data would make a major contribution to NASA's ESE and the U.S. Global Change Research Program. Information provides 'virtual ground truth' on land cover spectral properties in the spectral region used to produce spectral vegetation indices, and provides a direct link to the types of field measurements traditionally carried out by field scientists such as ecologists. These detailed aircraft measurements will permit field measurements to be scaled to coarser satellite sensor systems including IKONOS, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Landsat-7, and Moderate Resolution Imaging Spectrometer (MODIS). These images will provide the detailed spatial/spectral information needed to comprehensively characterize land cover conditions at EOS intensive study sites" (Goward et al., 1998).

2.2.1.4 Space Imaging, LLC

Space Imaging, LLC, of Thornton, Colorado, provides space-based 1-meter panchromatic and 4-meter multispectral images, image mosaics, and digital elevation models (DEMs) through an $11.3 million Phase II SDP contract. The IKONOS satellite collects data in visible and near-infrared bands at 11-bit radiometric resolution. Images can be provided at two levels of horizontal geometric accuracy. High spatial resolution, broad coverage (11 x 11 km scene), and the relative stability of a spaceborne platform provides significant potential for efficient land-use/land-cover mapping, as well as validation of coarser resolution systems.

The Phase II science assessment rationale for purchase of IKONOS data is as follows: "The IKONOS satellite data will make a major contribution to NASA'S ESE and the U.S. Global Change Research Program. IKONOS will be able to provide high resolution data that will be extremely valuable when scaling detailed ground observations to coarser resolution systems (Landsat TM and MODIS) and to support field campaigns carried out in support of missions such as EOS. The 1-meter panchromatic and 4-meter multispectral data will be highly complementary to current ESE missions due to its high spatial resolution. IKONOS has the advantage over aircraft-based systems by being able to image any location on the Earth's surface and to do this repetitively" (Goward et al., 1998).

2.2.1.5 AstroVision, Inc.

AstroVision International, Inc., of Bethesda, Maryland, was awarded a $1.4 million SDP Phase II contract. Upon the successful launch and operation of its satellite system, AstroVision will provide high-temporal-resolution full-disk imagery and higher-resolution imagery of regions of interest from geostationary orbit. The imagery is intended to support global monitoring and event monitoring of natural hazards, such as tornadoes, hurricanes, and volcanoes.

At the time of this writing, AstroVision has not yet launched its satellite system, and the contract has been canceled.

2.2.1.6 Licensing

Throughout the Phase II contract negotiation process, data licensing and distribution rights provisions were of great interest. Traditionally, NASA scientists and researchers were accustomed to the free and open distribution rights of non-military government-built remote sensing systems. However, free and open distribution rights significantly impacted the cost of commercial data to NASA. Thus, the majority of Phase II contracts included provisions that allowed data to be freely distributed only among NASA-affiliated researchers, with the exception of EarthSat data products, which could be freely distributed outside of the NASA community.

2.2.2 Outreach

Early in Phase II, NASA performed customers/constituents outreach to provide the ESE community with information about the SDP program. Outreach included presentations given to NASA Headquarters Code Y program managers, Goddard Space Flight Center Earth Sciences management, House and Senate Congressional Staffers, representatives from the Office of Management and Budget (OMB), researchers at the Landsat Science Meeting, the Earth Science Information Partners (ESIP) Working Group Meeting, the Goddard Institute of Space Sciences, the Earth Science Technology Office (ESTO), and the MODIS Science Meeting. In addition, mass-mailings were sent via email to ESE principal investigators, and an SDP web site (http://www.esad.ssc.nasa.gov/datapurchase/) was developed. The web site also functions as a data tasking, querying, and ordering interface for SDP data.

2.2.3 Tasking and Distribution

The NASA SDP data tasking, ordering, and distribution process is shown in **Figure 2**.

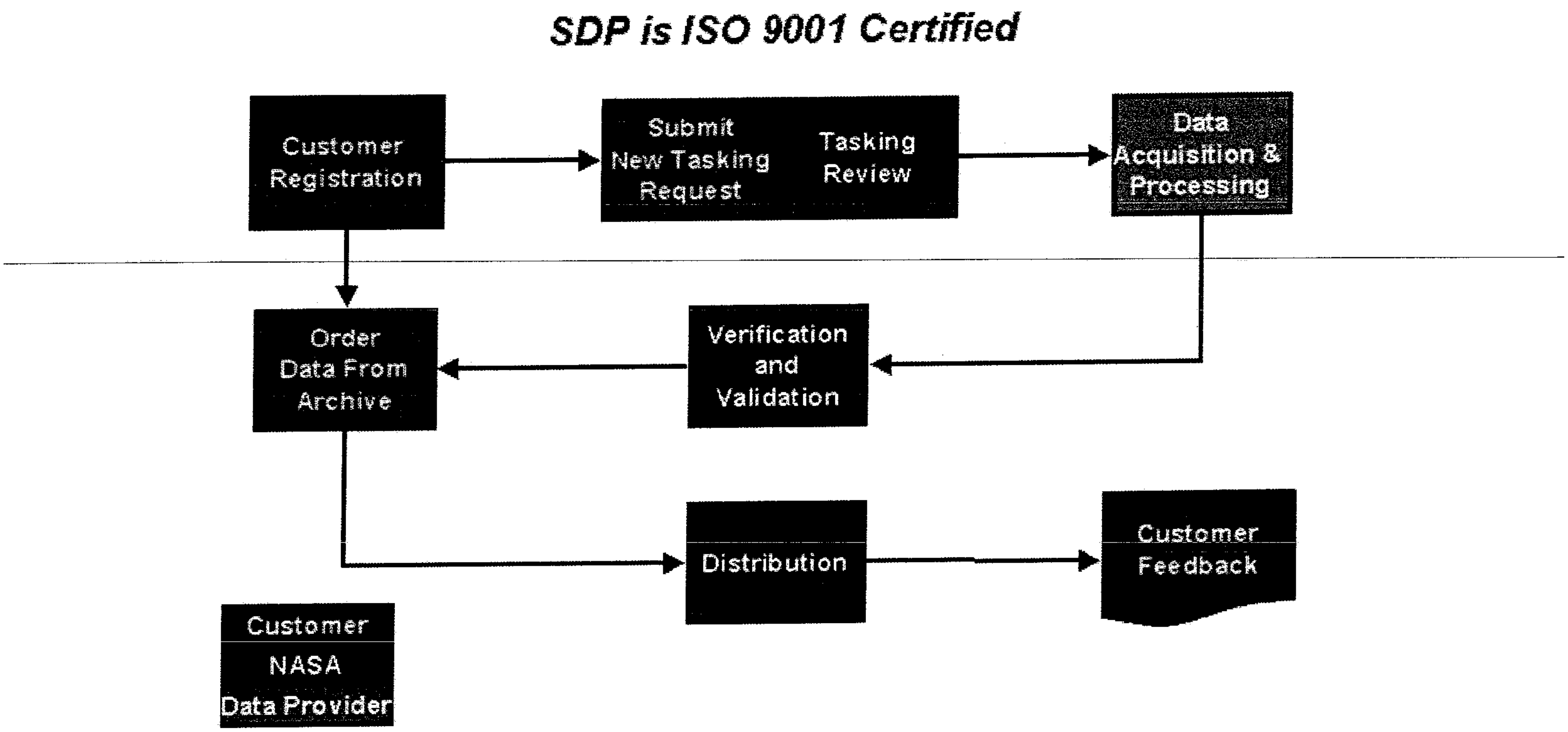


Figure 2. SDP General Process Flow.

Through the Scientific Data Purchase web site, NASA's affiliated researchers registered to become users of the SDP by supplying such information as organization, citizenship, and the NASA grant, contract, or agreement on which he/she was working so that SDP personnel could verify the user's ESE affiliation. Once the registration was approved, researchers also used the SDP web site to submit requests for data acquisition, called a task request. Task requests were reviewed by a Science Tasking Committee composed of NASA Headquarters ESE science and applications program managers, who evaluated the requested data's potential contribution to the research objectives stated in the request. After the Science Tasking Committee approved a task request, the requirements for data acquisition were sent to the appropriate data provider, who then acquired the data and delivered it to NASA.

Data received from the data providers was ingested into the SDP data management system. All SDP data products delivered to NASA underwent a thorough order verification and inspection process to ensure that the conditions of the contract and tasking request were met. The details of this process are described in **Figure 3**.

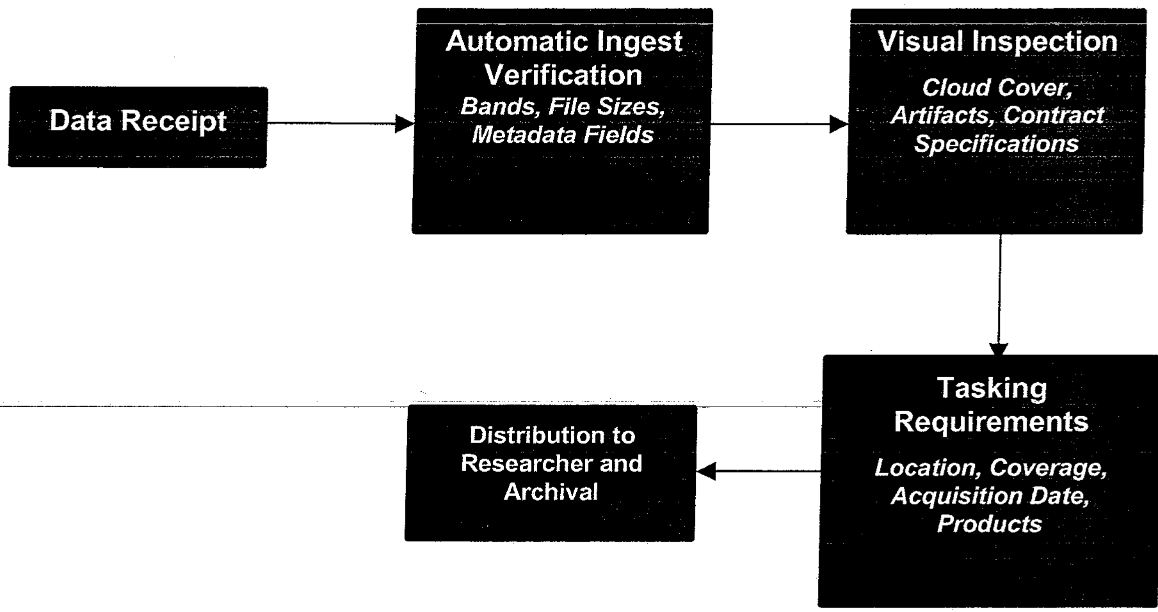


Figure 3. SDP Shipment Verification Process Flow.

Once data passed the inspection and shipment verification process, it was duplicated and sent to the researcher. A copy of each data set became part of the SDP archive and was made available for ordering by other registered SDP users. Additionally, the USGS Earth Resources Observation Systems (EROS) Data Center serves as the long-term archive for EarthSat Landsat orthorectified products purchased through the SDP. $3.6 million was provided to USGS EDC for the archive and distribution of EarthSat products.

2.2.4 Independent Data Product Characterization

An independent characterization was also performed on selected datasets for each of the Phase II contracts, and included laboratory characterizations of system performance and in-flight measurement of geopositional accuracy, spatial response, and radiometric accuracy using independent ground-based reference data. The characterization process was performed on selected datasets from each vendor as a way of monitoring the vendor's compliance with contract data specifications and ensuring data quality for science use. The centralized nature of the SDP program allowed personnel to characterize a representative sample of the datasets against these specifications. Details of the characterization effort are documented in several reports, publications, and workshop proceedings.

The EarthSat TM and MSS orthorectified datasets were assessed for geopositional accuracy using an independent set of government-provided ground control points. The ground control consisted of identifiable features within the ~30-meter TM imagery whose locations were accurately known. The known locations were compared to those defined by the TM imagery to determine if the imagery met the +/-50-meter absolute horizontal accuracy specification. The coarser spatial resolution of the MSS orthorectified products did not permit the identification of the same ground control features used for the TM accuracy assessment. Thus, to verify the accuracy of the MSS, selected MSS scenes were compared to the corresponding verified TM scene. In this analysis, it was assumed that if a particular TM scene was found to meet the +/-50 meter specification, that scene could serve as "truth" for verification of the corresponding MSS scene for the same area. Thus, the locations of identifiable features in the MSS scenes were compared to the location of the same feature within the TM scenes.

If the MSS-defined location of the feature was within +/-50 meters of the TM-defined location, it was determined that the MSS scene was within the +/-100-meter absolute horizontal accuracy specification.

Independent characterization of the DigitalGlobe/Intermap Star3i products included both a process review and product evaluation. A site visit to the Intermap facility was conducted by NASA to review data production processes and quality control measures. The processes at both Intermap and DigitalGlobe were registered to the ISO 9000 standard. In addition, the Star 3i system and data had previously undergone independent validation by other government agencies. Intermap performed periodic calibration flights over corner cube reflective targets to maintain system calibration throughout the SDP contract. The results of each calibration were delivered to NASA in the form of a report. NASA reviewed each report to verify horizontal and vertical accuracy for a range of antenna positions based on data from corner reflectors and transects of the calibration test site, as well as spatial resolution from corner reflectors. Additionally NASA performed independent product characterization on delivered Star3i products. Vertical accuracy of digital elevation models was verified for both flat and mountainous terrain using National Geodetic Survey (NGS) monument data from NOAA as the reference data. The NGS vertical position was compared with the vertical position for the same locations in the DEMs.

The Positive Systems ADAR 5500 camera underwent laboratory characterization in the NASA ESA sensor laboratory. Measurements of spectral response, dynamic range, linearity, and spatial response were performed in collaboration with Positive Systems personnel. The NASA laboratory characterization resulted in a modification to the sensor's spectral filters to improve performance and to ensure that the data met contract specifications. Characterizations of the sensor were also performed in flight. The in-flight spatial response was measured by acquiring data over specialized edge targets. Radiometric accuracy was determined through collection of ground reflectance and atmospheric data coincident to the data acquisition. An automated validation capability was also developed and utilized on all Positive Systems datasets. Spectral registration, ground sample distance, band-to-band registration, and fraction of saturated pixels were calculated during ingest of a dataset into the SDP data management system. Additionally, calculations of image endlaps and sidelaps were made for comparison with contract specifications.

Because Space Imaging, LLC, was the first company to successfully launch a spaceborne commercial high-resolution remote sensing system, there was a great deal of interest in understanding the IKONOS satellite's utility for science research and applications. Thus, NASA undertook a significant effort to characterize IKONOS performance independently. Several validation sites throughout the U.S. were used to characterize IKONOS data spatial response, geopositional accuracy, and radiometric accuracy. Scientists from the University of Arizona, South Dakota State University, and the University of Maryland contributed to NASA's characterization effort. These scientists brought years of experience in NASA Earth Observing System (EOS) calibration and validation. NASA-led vicarious calibration efforts determined that Space Imaging's initial radiometric calibration coefficients were inconsistent with those produced by the NASA team (Pagnutti et al., 2003). NASA collaborated with Space Imaging to investigate the inconsistency. As a result, the government-produced radiometric calibration results were incorporated into an updated set of Space Imaging calibration coefficients (Peterson, 2001).. NASA also collaborated with the National Imagery and Mapping Agency (NIMA) and the United States Geological Survey (USGS) – two government agencies utilizing IKONOS and other commercial data - to form the Joint Agency Commercial Imagery Evaluation (JACIE) team. The JACIE team collaboration resulted in a thorough characterization of the IKONOS system and improvements in data quality. (Zanoni et al, 2003). Additional information regarding JACIE is included in section 5.3 of this report.

3.0 Earth Science Enterprise Research and Applications Relevance

3.1 Data Use

To gain insight into how SDP data supported ESE science and applications, scientists utilizing SDP data were asked to categorize their research into one of the ESE Science Research or Application Theme Categories in place at that time. The Science Research themes included Land Cover-Land Use, Terrestrial Ecosystems, Solid Earth, Land Surface Hydrology, Physical Oceanography, Polar Environment, and Other. Application Research categories included Resource Management, Community Growth, Disaster Management, Environmental Quality, and Other.

The majority of research projects involved the Land Cover and Land Use Change theme area. Within this research theme area, data uses included the development of a national land cover database, the study of island ecosystems, the detection of selective logging sites, and the monitoring of changes in rivers, coastal wetlands, glaciers, and urban environments. In the Environmental Quality research theme area, SDP data was used to test water quality, study coral reef environments, and identify mosquito habitat location. In the Resource Management category, the data was used for precision agriculture and assessing forest inventories. The Terrestrial Ecosystems research theme area included projects that utilized SDP data to measure water, energy and carbon fluxes, to validate vegetative indices, and to generate global land cover products. SDP data was also used in support of several archaeology projects and Verification and Validation activities.

NASA renamed the Mission to Planet Earth enterprise to Earth Science Enterprise in 1998 (http://geo/arc.nasa.gov/sge/lansat/mtpe.html). The strategy behind renaming the enterprise was to coordinate research efforts towards the discipline of Earth system science, which includes studying the effects of natural and human-induced changes on the Earth's environment. Additionally, the name Earth Science more clearly conveys the goals and types of research the program was directed to conduct. The Earth Science Enterprise was organized to address key questions in major Earth system science disciplines: land surface cover, near-term and long-term climate change, natural hazards research and atmospheric ozone. With the release of the NASA Earth Science Enterprise Research Strategy for 2000-2010, the ESE program was re-divided into five disciplinary themes: oceans and ice, ecosystems, atmospheric chemistry, global water and energy cycle, and solid-Earth science. The ESE research program structured itself in alignment with the U.S. Global Change Research program (USGCRP), with some overlaps and some differences, to insure research addressed primary Earth System science issues and questions. In addition, the current ESE includes an Application Division which extends the benefits of NASA science and research technologies by identifying12 National Applications whereby practical uses of remotely sensed systems and corrseponding data predictions could be applied.

During the course of the SDP data use was categorized by the MTPE science and applications themes. However, as demonstrated by the following sectio, use of SDP data spanned a wide range of research and applications relevant to both past and present NASA Earth Science goals.

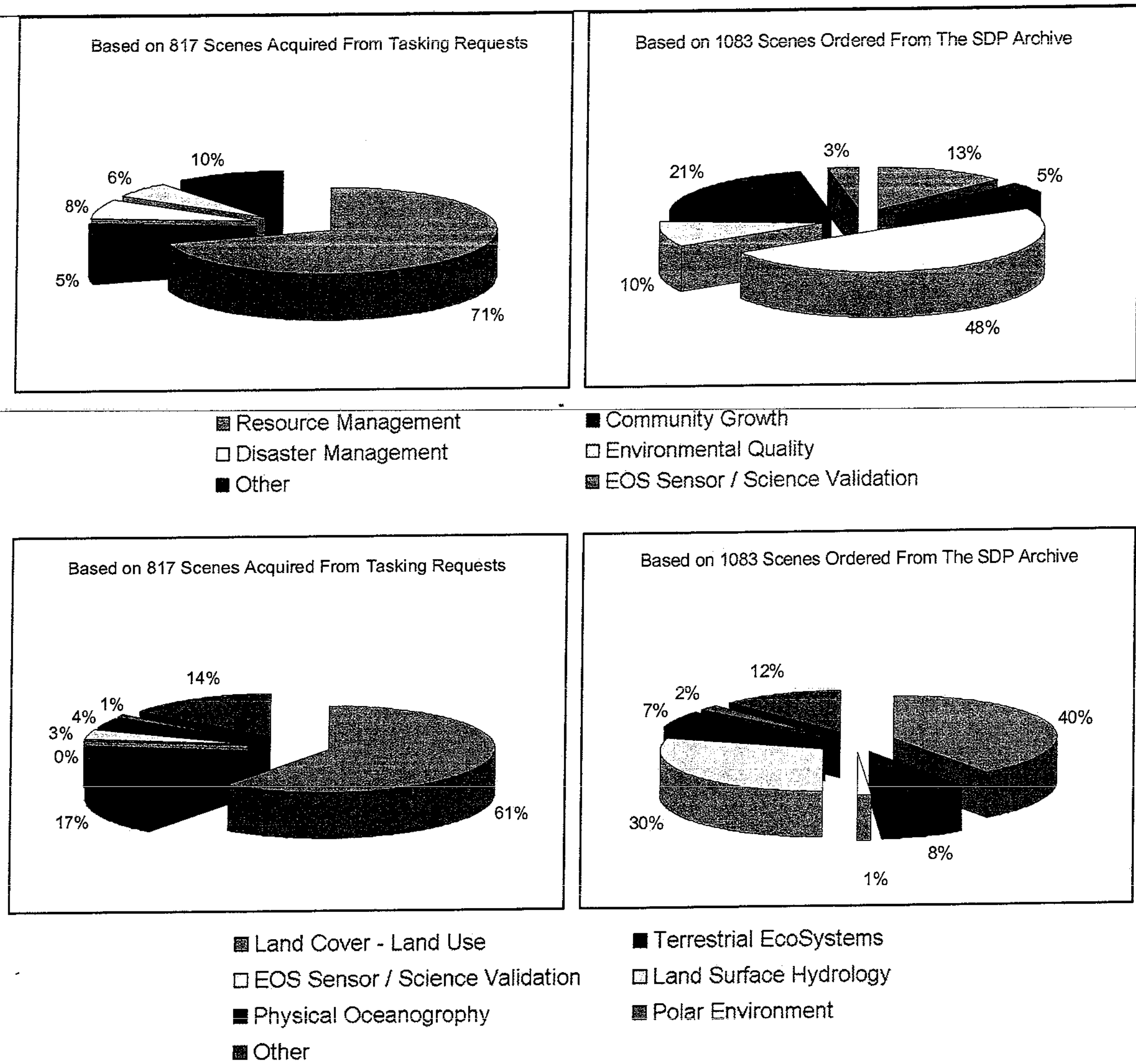


Figure 4. Piecharts represent the data Use percentages subdivided by the applications research category (top) and the science research category (bottom).

3.2 Earth Science Research and Applications Project Examples

Several SDP projects are described below, categorized by data vendor. They illustrate examples of both the SDP data use and the impact of the SDP data on research projects.

3.2.1 Earth Satellite Corporation

The EarthSat SDP products have provided, for the first time, complete global coverage of orthorectified Landsat TM and MSS data. EarthSat purchased data from foreign ground stations; this data has never before been contained in the U.S. archive. Through the SDP, EarthSat provided NASA affiliated researchers with orthorectified Landsat data, which has been used in a variety of ways.

<u>Global Land Cover</u>

The Global Land Cover Facility (GLCF) in College Park, Maryland, is a funded member of NASA's Earth Science Information Partnerships program whose research emphasis has been to address critical global and regional scale terrestrial Earth systems science issues that are central to NASA's Earth Science Enterprise. One of GLCF's foremost roles has been to enable the pursuit of Earth science research through the distribution of high quality raw and derived datasets, such as global land cover products. Through its extensive infrastructure and partnership with the University of Maryland Institute for Advanced Computing Studies, the GLCF has utilized the latest data distribution technologies. Through NASA's SDP, the GLCF's research projects have been enhanced by the availability of Space Imaging's IKONOS and EarthSat GeoCover products. In some cases, EarthSat data has allowed coregistration of Landsat 7 imagery to provide higher quality time series. In other cases, the data has provided the GLCF and its user community with and effective resource for validating coarse-resolution products.

Over the past several years, the GLCF, in partnership with NASA's SDP, has made it its goal to build a robust body of products and services for the Earth science community. The availablity of multiple characterizations of the Earth's surface and, most recently, the EarthSat orthorectified TM coverage, has led to a better understanding of the Earth and the manner in which it is changing. Synoptic coverage of the Earth's forest cover, in combination with the EarthSat GeoCover coverage obtained from SDP, has enabled natural resource managers at the local and national levels to better understand forest dynamics (**Figure 5**). When one considers that some of the more inaccessible areas of the Earth are of considerable interest to researchers because of their preservation or conservation value, high-resolution remote sensing emerges as a viable alternative to ground study.

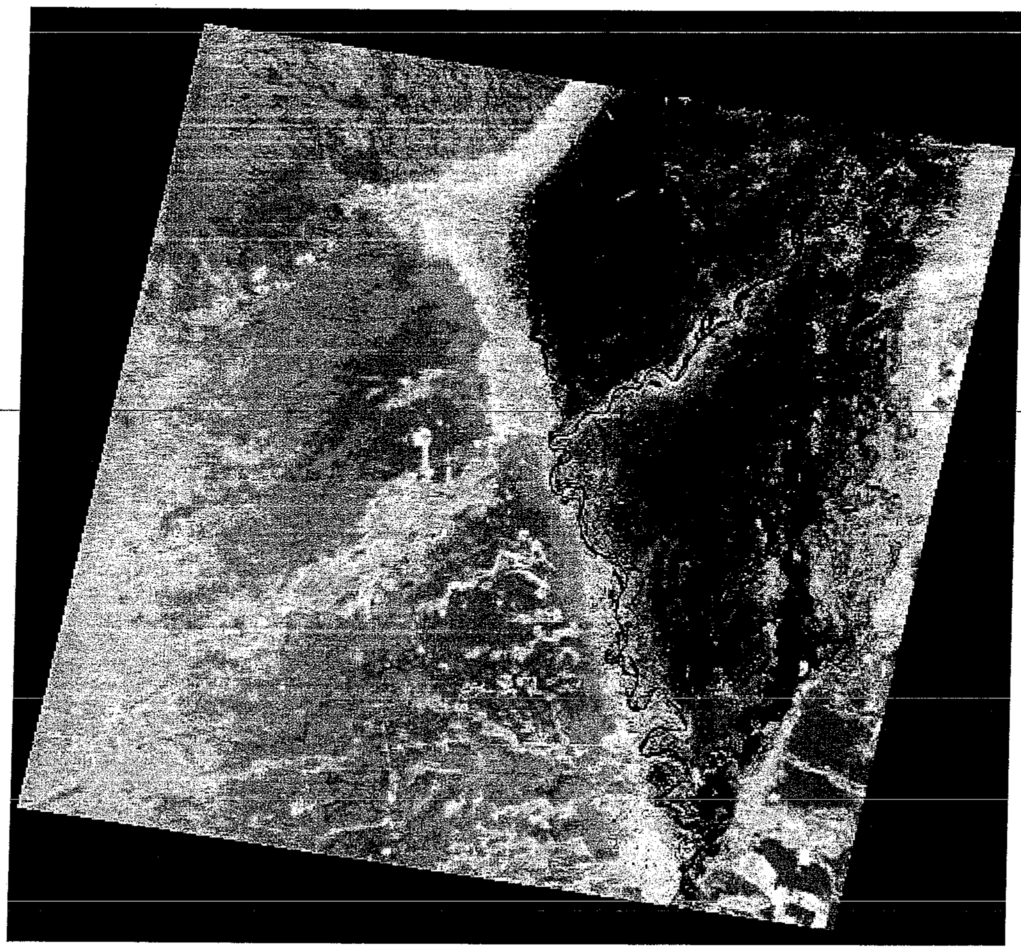


Figure 5. EarthSat GeoCover Landsat 4 image acquired on May 10, 1989, showing the intersection of Bolivia (north/northwest region), Paraguay (south/southwest region), and Brazil (darker region to east). This image has been used to analyze deforestation and land cover change and is an example of how humans and the environment interact.

Ground-level Ozone Effects

Imagery from EarthSat provided the necessary data for a project conducted by NASA-affiliated researchers at the University of Rhode Island titled "The Effecting Factors on Ground-level Ozone in the Northeastern United States." The study was designed to develop innovative models in regional land use and land cover change study. As part of the research, the impact of land use and land cover change on the environment was investigated; specifically, the factors influencing the concentration of ground-level ozone in the northeastern United States. Remote sensing observations have rarely been used to quantify the effects of natural and human factors on the spatial variability of ground ozone. However, the SDP data was used to extract land cover information of the Northeastern U.S., including the states of Massachusetts, Rhode Island, Connecticut, New Jersey, Delaware, the District of Columbia, as well as part of New York, Pennsylvania, and Virginia. Urban land cover change between 1990 and 1999 was examined for this region. This project revealed a relationship between the urban land cover change and the ground ozone dynamics. The results revealed that a positive correlation between land surface temperature, which is affected by land-cover change, and ground ozone concentration exists, and that urban sprawl, in particular, is one of the factors that caused the ozone problem in the region. EarthSat GeoCoverLandsat data (**Figure 6**), as a single data source, provided homogeneous regional coverage with the same spectral bands; in this way a large regional phenomena could be studied under the same conditions. Such unified regional coverage has not been available from other sources—check with Bob.

Figure 6. EarthSat GeoCover Landsat TM imagery displaying the study area location for a University of Rhode Island project titled "The Effecting Factors on Ground-Level Ozone in Northeastern United States."

Terrestrial Carbon Storage in Russia

Researchers at the Geographic Information System (GIS) & Remote Sensing Laboratory at Woods Hole Research Center, Woods Hole, Massachusetts, have studied land-use change and changes in terrestrial carbon storage in Russia. These changes have occurred as a result of recent environmental disturbances. The carbon balance of northern mid-latitude terrestrial ecosystems remains uncertain; recent estimates vary as to whether the region is a source (an extra source of carbon) or a sink (where carbon is absorbed). By integrating EarthSat Landsat data (**Figure 7**), forest inventory data, results from ecological studies, agricultural and forestry data on land use change, and MODIS satellite data and products, researchers hope to determine the current distribution of carbon storage and changes in the storage over the last decade. Researchers stratified Russia into 25 regions using four geographic blocks (European, West Siberia, Central Siberia, and Eastern) and subset the blocks further by forested vegetation zones. They sampled 15 of those regions using forest inventory data and Landsat data to create continuous biomass layers; these samples will form the basis for a Russia-wide carbon distribution map using MODIS data. The work thus far encompasses 4 sites: one region in Leningradsky, one region in Kursk, and two regions in Khabarovsk.

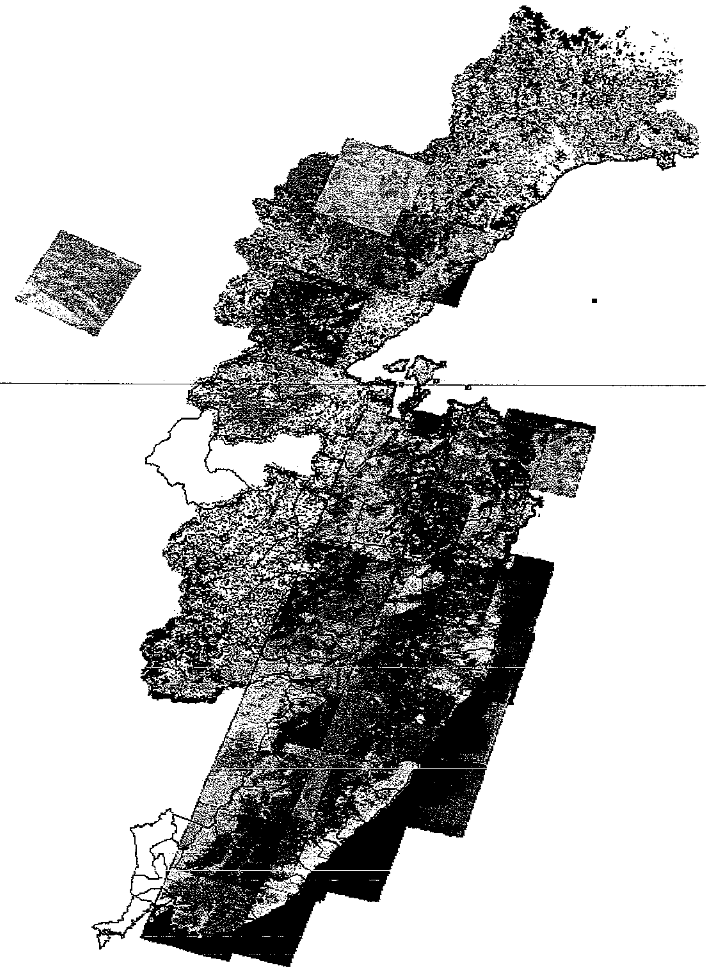


Figure 7. EarthSat GeoCover Landsat TM data overlaid on a SPOT land cover classification captured over a study area in Russia for the project titled "Changes in Terrestrial Carbon Storage in Russia as a Result of Recent Disturbances and Land-Use Change."

Remote Sensing Imagery for Sustainable Development

The Center for Geographic Information System (GIS) and Remote Sensing at University of South Carolina (USC), which combines the campus-wide GIS support program, the campus University Consortium on Geographic Information System initiative, and the existing NASA-sponsored Affiliate Research Center (ARC), was formed in 2000 to focus on GIS and remote sensing topics.

One of USC's GIS and remote sensing project sites is the Tanzania/Kenya coastal zone; this area is a part of the U.S. Government's Geographic Information for Sustainable Development (GISD) initiatives.The challenge of coastal region studies lies in arriving at enduring solutions to the complex problems facing these unique areas, where considerable ecosystem services and high human population pressure coincide. The goal of the Tanzania/Kenya project is to combine remote sensing data with GIS technologies for use in coastal resource management, planning, and decision making. The research findings from this project were compiled into The National Academy of Sciences (NAS) report titled "Down to Earth-Geographic Information for Sustainable Development in Africa" (cite) and was published in hard-copy and presented at the World Summit on Sustainable Development (WWSD) in Johannesburg, South Africa in September 2002 and elsewhere.

In order to develop sustainable development projects, it is essential to have fundamental framework data. This normally takes the form of "framework-foundation-data" consisting of (a) geodetic control, (b) ortho-imagery, and (c) digital elevation and bathymetry data. The National Academy committee concluded, in the above mentioned report, that the most important global dataset available for (b) ortho-imagery was the GeoCover ortho imagery dataset prepared as part of the NASA's SDP Program by Earth Satellite Corporation (**Figure 8**).

The NAS report describes in detail the significance of the global dataset and how it is shared by NASA and others at a minimal cost through a very effective user-interface. It is the only true relatively high spatial resolution dataset (approximately 30 x 30 m) global orthoimage dataset that can be used by most developing countries as a very important starting point in sustainable development projects. The report also describes other critical "thematic-framework-information" of significance for most sustainable development projects. One of the most important is land cover. It became clear that the global Landsat GeoCover land cover dataset prepared by EarthSat available in the NASA's SDP program is the only global land cover dataset at approximately 30 x 30 m. Thus, this derivative product is very important on a global basis for sustainable development projects. Many times it is the only relatively accurate land cover database available for entire countries. EarthSat is also completing a 2000 version of the land cover dataset.

Figure 8. EarthSat GeoCover Landsat TM data captured over the Tanzania coastal area in June 1991.

Forest Health and Land Use Change

The cover of the September 2000 issue of *Photogrammetric Engineering & Remote Sensing* presented an Earthsat Landsat TM mosaic compiled from 1275 scenes from the NASA SDP (**Figure 9**). This dataset has also been used for change detection research being performed by the United States Department of Agriculture (USDA) Forest Service. In 1994, a formal agreement between the Forest Service and East Africa led to the creation of the Forest Health Center in Nairobi. In September 1999, another formal agreement was developed between the Forest Service and the Faculty of Forestry and Nature Conservation, Sokoine University of Agriculture. In February 2000, the Forest Service began a two-year evaluation of forest health and land-use change in the Eastern Arc Mountains of Kenya and Tanzania. Main components of this study include satellite imagery, permanent plots, and a Web page. Under a NASA-USDA Memorandum of Agreement, the Forest Service used the EarthSat imagery from the SDP for this study. Analysis of the 1980s TM and 1999 TM imagery showed a forest area reduction of over 30 percent. For more information, see http://www.easternarc.org/html/usfs.html.

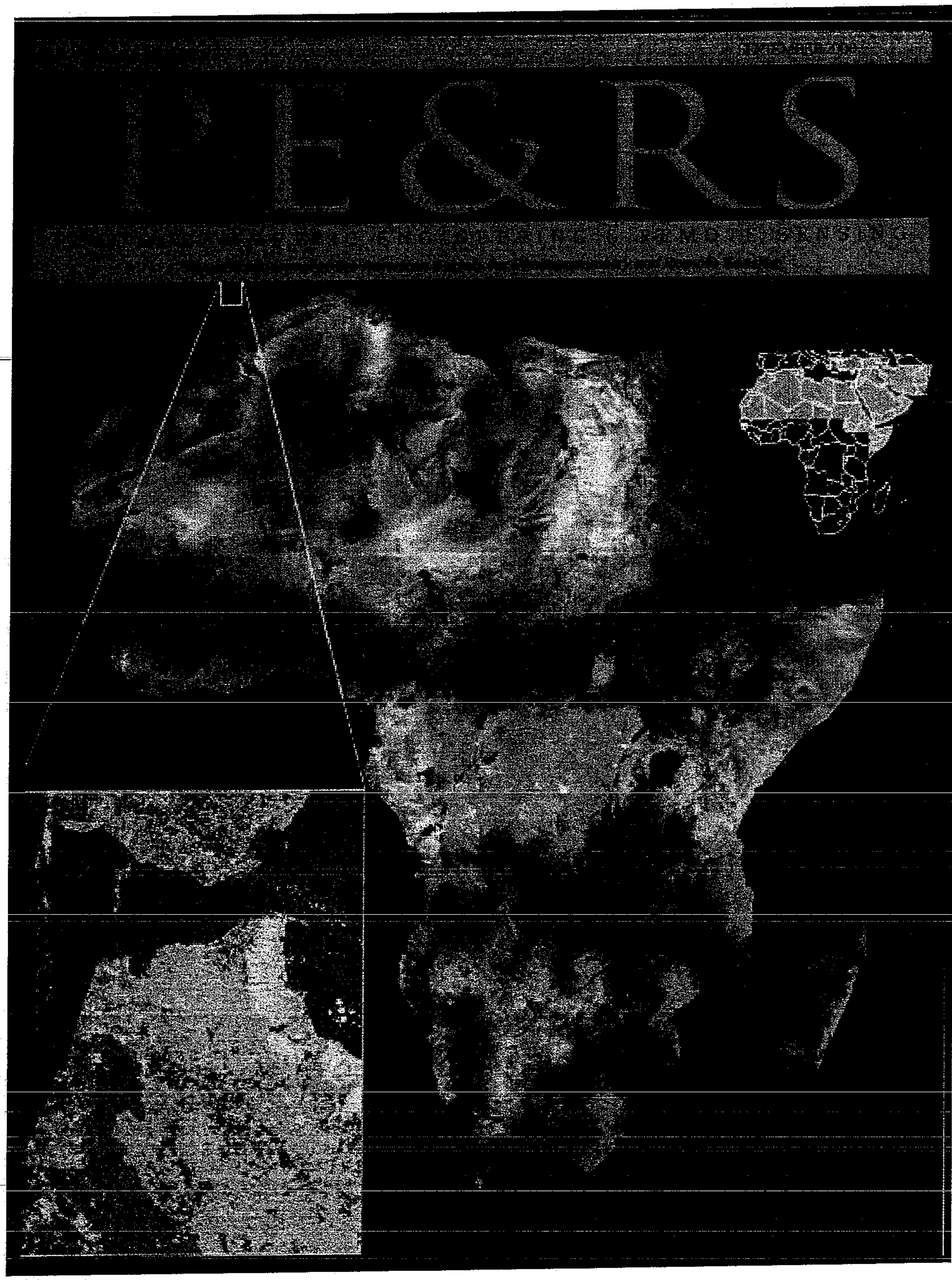


Figure 9. EarthSat GeoCover Landsat TM mosaic compiled from 1275 scenes acquired by EarthSat accompanied a cover story in the September 2000 issue of *Photogrammetric Engineering & Remote Sensing.*

NASA-CCAD Mesoamerican Biological Corridor Project

In 1998, NASA signed a Memorandum of Understanding with the Central American Commission on the Environment and Development (CCAD) in support of cooperative research focused upon monitoring the Mesoamerican Biological Corridor (MBC). In this effort, NASA and CCAD collaborated to utilize remote sensing technologies to map and monitor land cover of the MBC. This region has suffered from high rates of deforestation because of human migration and agricultural expansion. The goal of the collaboration between NASA and the CCAD has been twofold: (1) to conserve, protect, and help to balance ecologically the environment by developing regional forest cover maps and to monitor changes in forest, and (2) to use this information to help sustain economic development. Working in conjunction with the University of Maine in Orono, Maine, NASA's Office of Earth Science has been helping to create a regional satellite database to monitor forest condition and environmental change throughout the MBC. By using remote sensing data provided through NASA's SDP, this region's first detailed land-use maps have been developed.

The EarthSat GeoCover SDP ortho-rectified TM imagery was essential to the success of the NASA/CCAD project. SDP images were acquired for the 1990s, and TM scenes were purchased for 2000, to analyze forest cover and deforestation within the MBC (**Figure 10**). The results of the forest cover and change detection were published and used by Central American government and conservation organizations to develop conservation strategies concerning sustainable forest management within the MBC. Spatial information about the status of forest cover in the MBC was never available before and convinced the Central Americans that NASA remote sensing technology was an essential tool needed to continuously monitor natural resources throughout the region.

The EarthSat GeoCover TM data was also used to develop a quality remote sensing training program for Central American scientists on how to map land cover and deforestation using images for each of the seven countries. As a result of the successful training program and applied research leading to an assessment of forest cover and change in the region, CCAD and U.S. Agency for International Development (USAID) are funding the University of Maine and Oregon State University to conduct an expanded land cover, change detection and carbon monitoring project for the region.

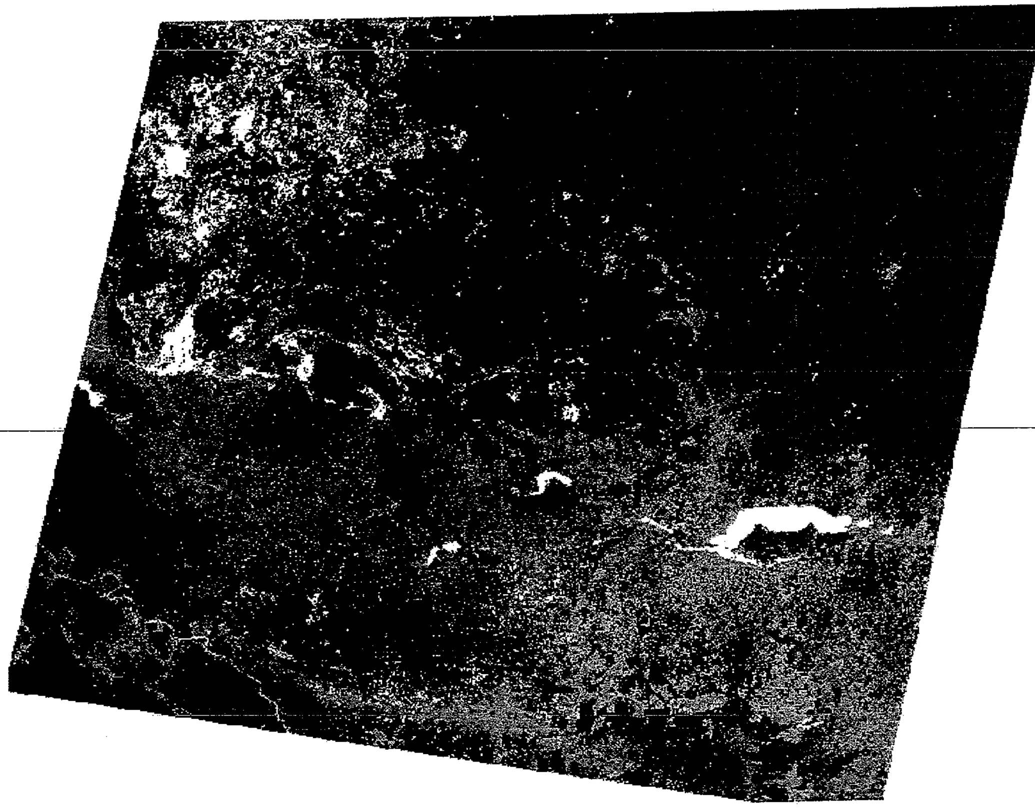


Figure 10. Land Cover Change Classification over Central America created using EarthSat GeoCover Landsat imagery from 1986 and Landsat data from 1997. The green represents forest, the gray represents non-forest, and the red represents forest clearing between 1986 and 1997.

Calibration/Validation Research: Uniform Site Identification

As part of the John C. Stennis Space Center (SSC) independent validation effort, scientists at NASA's SSC have used the EarthSat GeoCover African TM scenes to identify uniform sites for vicarious calibration and signal-to-noise (SNR) studies. Particular sites in Libya exhibited very high uniformity, thus facilitating the tasking of Space Imaging's IKONOS satellite over these sites to explore radiometric calibration and SNR assessments. The sites exhibited such uniformity that slight differences in gain coefficients between focal plane arrays on IKONOS could be observed (**Figure 11**). Space Imaging has since corrected these differences. This study demonstrated that the global EarthSat GeoCover dataset could be used to identify uniform sites for potential use in radiometric characterization.

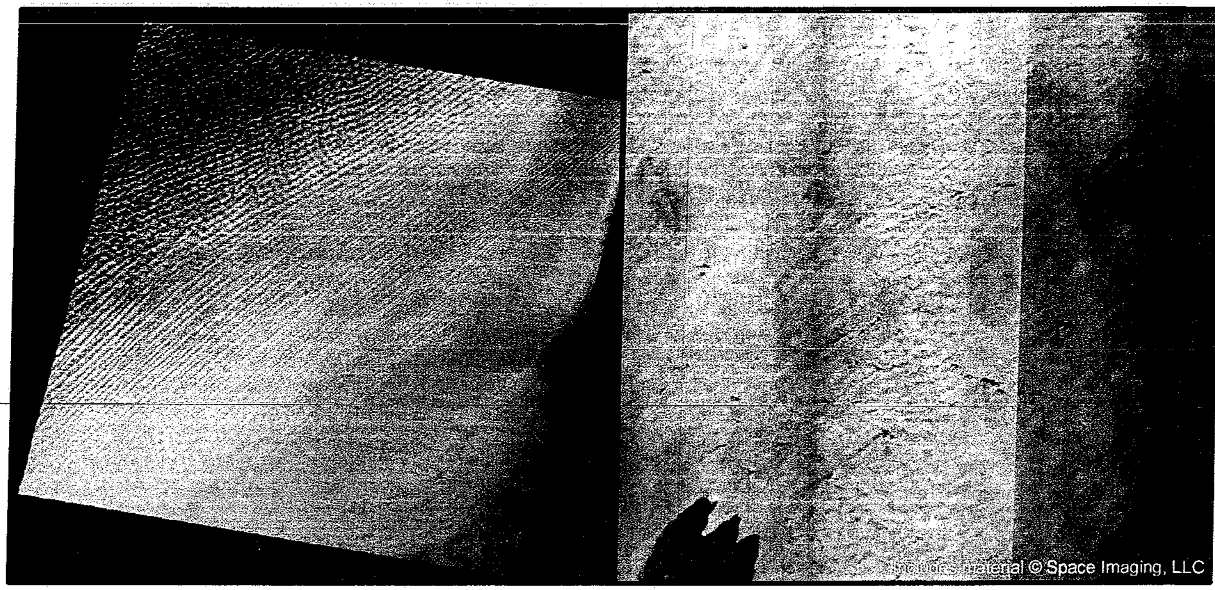


Figure 11. EarthSat GeoCover Landsat TM scenes over Africa used to identify uniform sites to assist in IKONOS validation efforts. Left: Most uniform ~11 km x 1 km area "Libya 1" identified by yellow rectangle (RGB: 3,2,1). Right: IKONOS image centered over the ~11 km x 1 km area found in the Landsat TM analysis (RGB: 3,2,1).

Identifying Possible Terrorist Locations

Counter-terrorism work utilizing EarthSat GeoCover imagery has improved the existing maps of the northwest Pakistan-Afghanistan border area. Using background scenes from video footage, regional cultural geography, and military history gained from extensive fieldwork in Paktia and Paktika (provinces of eastern Afghanistan), NASA-affiliated researchers at the University of Cincinnati have acquired imagery to determine possible terrorist locations in the volcanic rocks of eastern Afghanistan. The imagery was imported into a geographic information system (GIS), and the public NIMA geographic database was superimposed on the imagery to determine the regional extent of these volcanic-like rocks. A short list of likely targets was then forwarded to the United States government in October 2001. This combination of remotely sensed geology and geography may develop as a tool that will have a significant impact on the fight against terrorism.

Virtual Exploration of the U.S.

A NASA ESE partnership project with the USGS used EarthSat data to create a CD set of GeoCover imagery titled "United States of America Digital Landsat Mosaics." This CD set allows the viewer to explore the entire United States from a variety of scales ranging from states and regions to individual cities and towns. The perspective view from the Landsat series provides new insight on the land surface conditions of the United States to decision makers, teachers, and students who wish to enhance, protect, and explore our country. Approximately 3000 CD sets are currently in production. These CD sets have been sent to NASA Headquarters, to the SSC Education Office, and to the USGS EROS Data Center (EDC). NASA Headquarters will distribute 535 sets to members of Congress, and the EDC will distribute the CD sets to the public. For examples, see **Figure 12.**

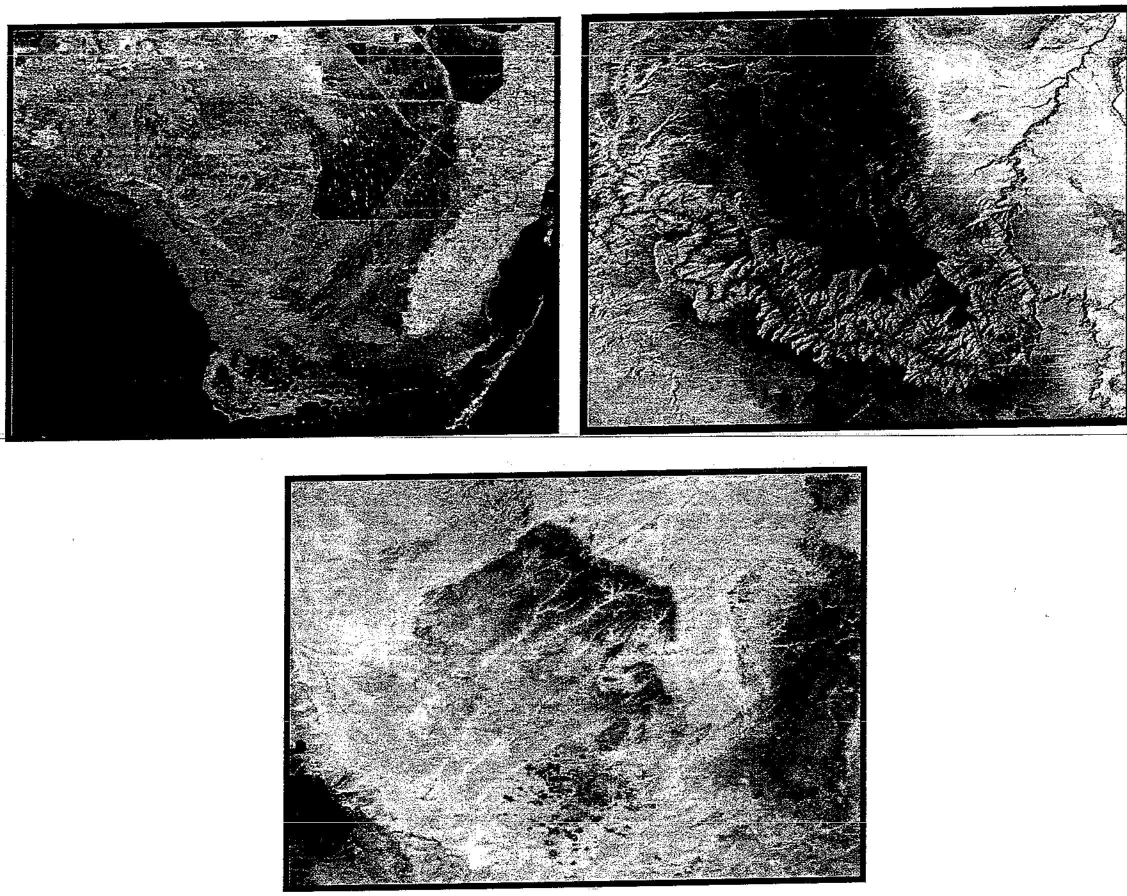


Figure 12. Mosaics of EarthSat GeoCover Landsat TM data captured over the Florida Everglades (top left), the Grand Canyon (top right), and the Painted Desert in northeastern Arizona's Petrified Forest National Park (bottom image). These mosaics were created for the "United States of America Digital Landsat Mosaics" CD set.

3.2.2 Digital Globe/Intermap

The Digital Elevation Models (DEMs) available from Digital Globe/Intermaps' STAR-3*i* sensor have proven to be invaluable in many fields of research. STAR-3*i* has provided imagery of Alaska that, in the past, has not been available. (NASA's Shuttle Radar Topography Mission (SRTM) did not acquire imagery at high latitudes.) Additionally, STAR-3*i* has provided imagery of volcanoes in Java, Indonesia, that simply cannot be acquired from existing, non-classified spaceborne systems. STAR-3*i* has also been used over Central America to assess deforestation and has been instrumental in glaciological research directed toward studying the effects of global warming.

Solid Earth Applications: Alaska Aviation Safety

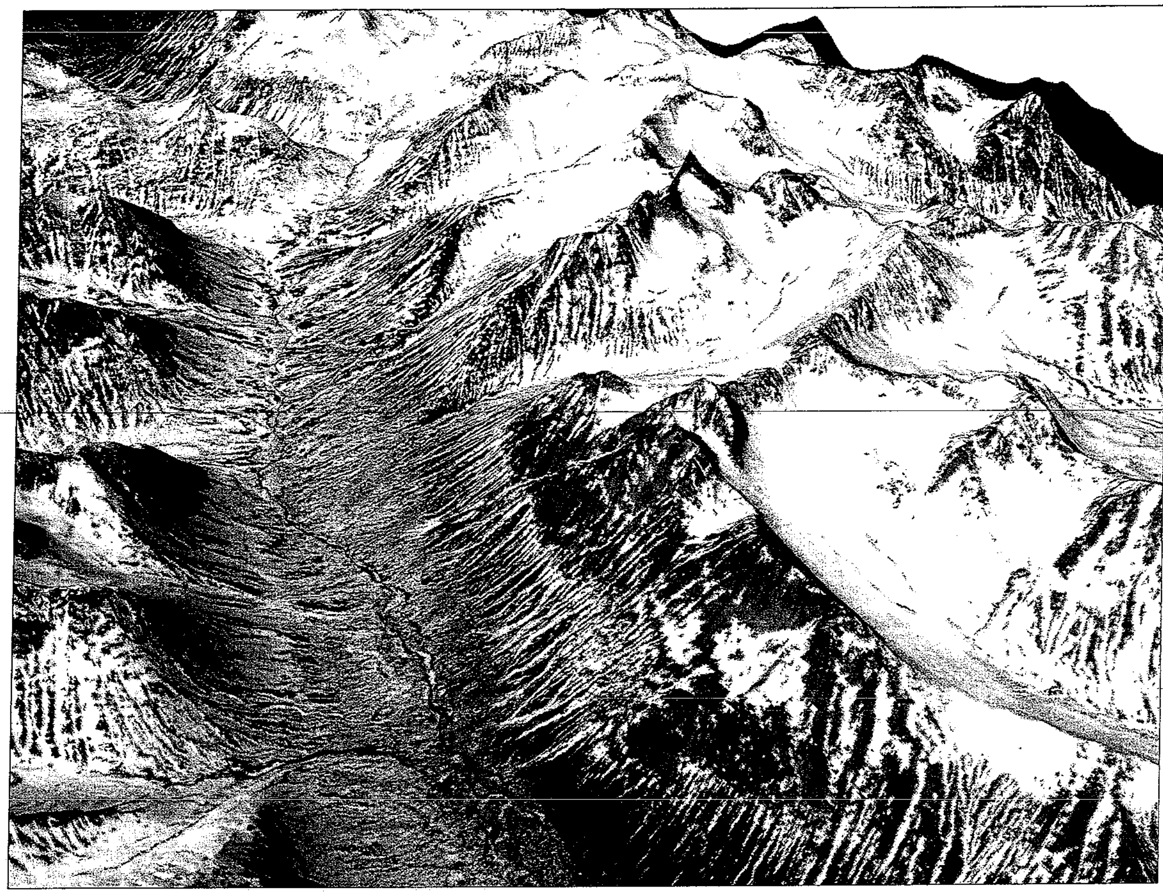
NASA's Langley Research Center's (LARC) Aviation Safety Program (AvSP) has partnered with the Federal Aviation Administration (FAA), aircraft manufacturers, airlines, and the Department of Defense. This partnership supports the national goal announced by President Clinton in February

1997 to reduce the fatal aircraft accident rate by 80 percent in 10 years and by 90 percent over 25 years (http://www.aero-space.nasa.gov/goals/safety.htm).

The Synthetic Vision Project is an aviation safety project that is being conducted by NASA's AvSP.. Most fatal aircraft accidents result primarily from limited visibility; the availability of synthetic vision could potentially reduce low-visibility conditions as a contributing factor in aircraft accidents. The state of Alaska has very few roads, and travel throughout the state relies heavily upon aviation. The Alaska flight corridors have a limited number of mountain range passes that are used for flight; these corridors must be used in even the most inclement weather conditions. Consequently, crash statistics reveal that these particular flight corridors have reported many aircraft crashes.

NASA's AvSP is helping to develop a synthetic vision system, or a virtual-reality display system, for aircraft cockpits. Synthetic vision systems (SVS) use aircraft attitude information derived from onboard sensors and position obtained from GPS, to portray a clear, daylight representation of the out-the-window scene on a graphics display device in the cockpit, greatly improving the pilot's situational awareness. Crucial to making this concept work are the underlying terrain, obstacles and airport databases that are queried by the system to synthesize the outside environment for display to the pilot.

STAR-3*i* high-resolution digital elevation imagery of these corridors have been made available to the AvSP through NASA's SDP and a 3-D visualization concept has been developed to help train pilots to fly through difficult flight corridors that are unique to Alaska's landscape. The SDP data was collected in Alaska is being used by the SVS project to generate the required databases for simulation testing of the Juneau, Alaska region in support of the FAA Capstone program and of various Alaskan mountain passes to support local research into terrain portrayal and symbology for head down displays. Special databases were generated that are used by the SVS displays mounted in front of the pilot in the cockpit, and others were developed to provide out-the-window views for various flight simulators. Depending upon the intended use, the 3D databases are either colored based on elevation or are draped with photographs or high resolution IKONOS satellite imagery (**Figure 13**) also acquired through the SDP.



Includes material © Space Imaging, LLC

Figure 13. DigitalGlobe/Intermap STAR-3*i* IFSAR terrain model draped with IKONOS imagery acquired in Alaska used for flight scenarios for the Symbology Development-Heads Down Display simulation experiment.

Solid Earth Applications: Volcanic Topography

The Hawaii Institute of Geophysics & Planetology used the DigitalGlobe/Intermap STAR-3*i* imagery over Java, Indonesia, to validate NASA EOS Interdisciplinary Science Team Investigations. The team's effort includes working on the development of algorithms to study volcanoes. The data requested through the SDP program enables the study of the topography of different volcanoes in Java at a horizontal and vertical resolution that cannot currently be obtained by spaceborne methods. The imagery focuses on mapping hazards at some of the world's most active volcanoes to understand how these volcanoes change after large eruptions. The imagery is also being assessed for mapping potential active volcanic regions. An example image set of a volcanic region is shown in **Figure 14**.

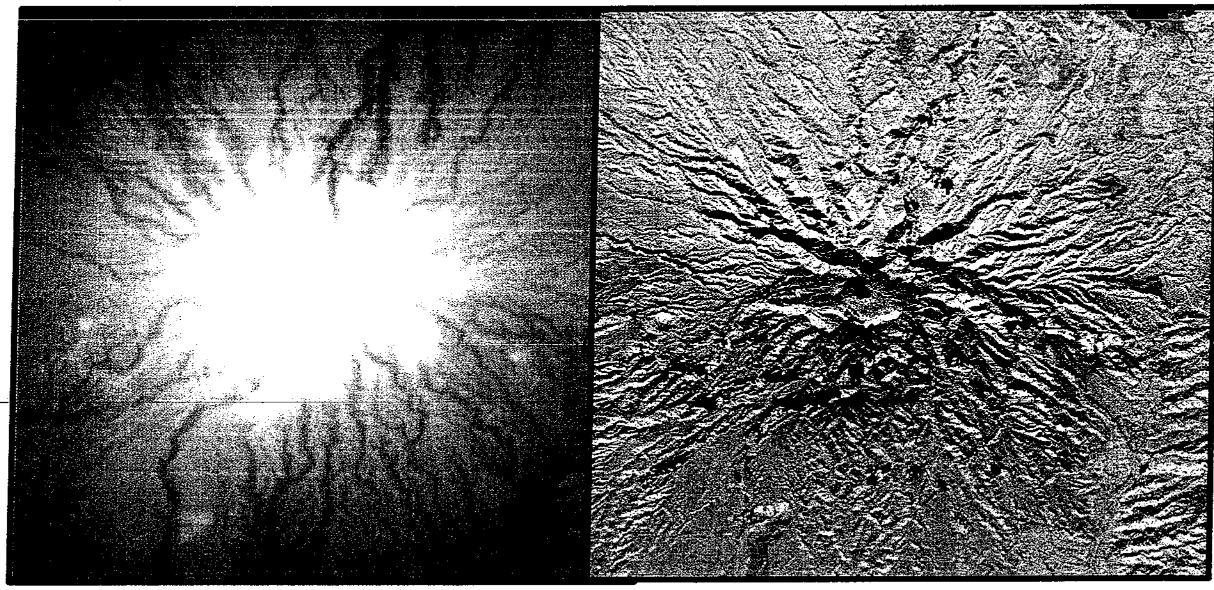


Figure 14. DigitalGlobe/Intermap STAR-3*i* digital elevation model and orthorectified radar image map over Java, Indonesia.

Arctic Region Hydrology

The Alaska Synthetic Aperture Radar Facility (ASF) is located in the Geophysical Institute at the University of Alaska in Fairbanks, Alaska, and is primarily funded through NASA's Earth Observing System. The ASF's primary mission is to acquire, process, and archive satellite imagery to advance polar research and Earth science. Assessments of the role of terrestrial hydrologic processes in climate change and, in particular, the processes unique to Arctic hydrology are lacking. Studies for hydrological and permafrost research have been severely limited because of the low resolution of DEMs available for these study areas. However, with the availability of DigitalGlobe/Intermap STAR-3*i* high quality DEMs through NASA's SDP, previously impossible computer modeling is now possible. Studies that involve assessing regional impacts of climate change using a combination of image analysis and field validation within Alaska have now been enabled

Driven by scientific interest in high latitude climate change, and its impact on global climate change, a series of intense hydrologic studies have been ongoing in the Kuparuk River watershed on the North Slope of Alaska (funded presently by National Science Foundation (1993-present) and initially by Department of Energy (1985-1992)). The acquisition of the STAR-3*i* DEM of this basin has allowed the study of many detailed hydrologic processes, previously not possible. Furthermore, because of the higher resolution the STAR-3*i* DEM data has over the USGS DEM, the most advanced spatially distributed hydrologic models to generate both drainage networks and areas for the four catchments being studied were able to be used (Imnavait Creek, Upper Kuparuk River, Kuparuk River, and Putuligayuk River; **Figure 15**). Because these are relatively young surfaces and underlain by permafrost, the drainage networks are poorly developed both in the foothills and coastal plain, making a high resolution DEM a requirement for even the most basic hydrologic analysis. Topography is very important to many hydrologic processes such as soil moisture distribution and snow distribution; having precise DEM data enables the routing of soil moisture in the active layer above the permafrost and redistributes the heterogeneous snowpack by modeling the windy environment using accurate slopes and aspects provided by the DEM. In summary, the STAR-3*i* data

has enabled the conduct of essential hydrologic research, analysis and modeling, at a previously impossible level of detail on a large scale Arctic watershed.

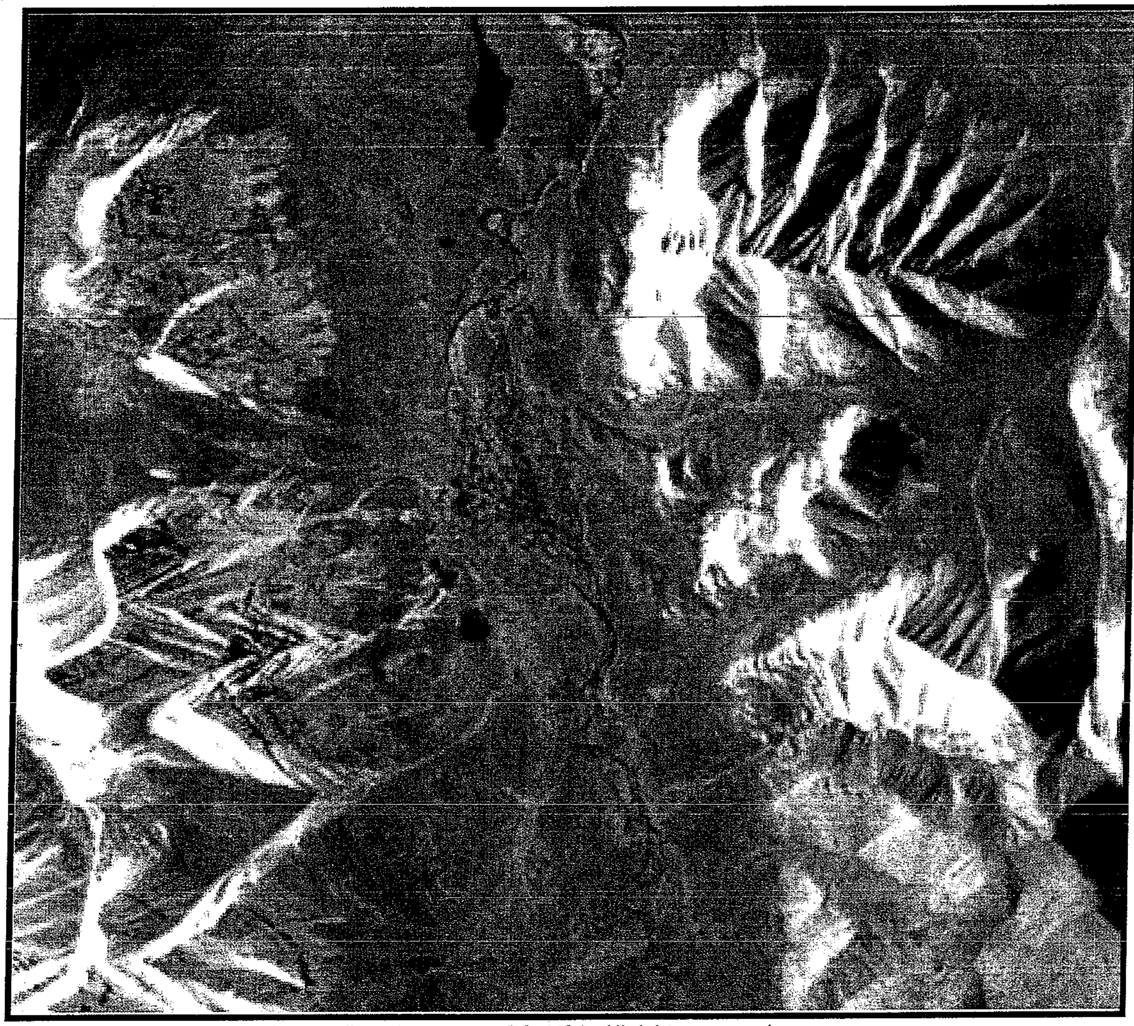


Figure 15. DigitalGlobe/Intermap STAR-3*i* orthorectified radar image map captured over a study area in Alaska for a project titled "Kuparuk River Basin: Watershed-Scale Analyses of an Arctic Drainage-A New High Resolution Digital Elevation Model."

NASA-CCAD Central American Archaeology

NASA's Central American Commission on the Environment and Development (CCAD) has used STAR-3*i* imagery over nine sites in seven countries for mapping natural, historic, and other cultural resources. Traditional archaeological survey techniques have become inefficient and costly. Remote sensing helps achieve archaeological research objectives, which involve detecting, mapping, locating and analyzing associated landscapes. The Star3i data has been used to map several previously unknown archaeological sites, to assess deforestation, and to map hurricane damage. One thousand years ago, the forests of the Peten were nearly destroyed by the ancient Maya, who after centuries of successful adaptation finally overused their resources. After centuries of regeneration, the Peten now represents the largest remaining tropical forest in Central America. However, current inhabitants are abandoning the successful adaptive techniques of the indigenous population in favor of the destructive techniques of monoculture and cattle raising, resulting in rapid deforestation. Remote sensing and GIS analysis are being used to address issues in Mayan archeology as well as to monitor the effects of increasing deforestation in the area. The data has also provided an improved base map for registering other geospatial data. Through the use of remote sensing/GIS analysis, researchers are attempting to answer questions about the past to protect the resources of the future (**Figure 16**).

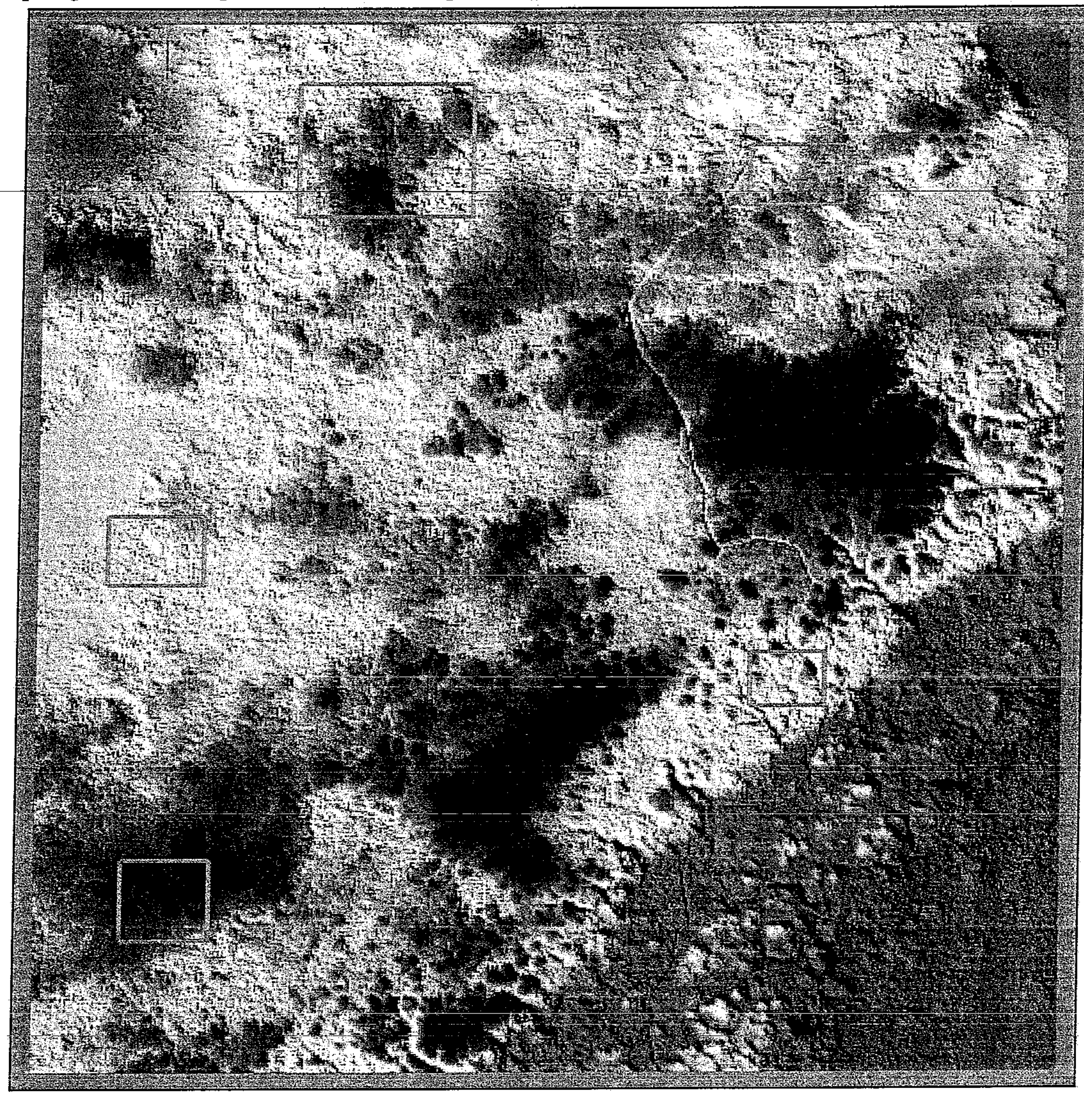


Figure 16. DigitalGlobe/Intermap STAR-3*i* digital elevation model of Rio Bravo Reserve in Belize. Mayan ruins are shown in cyan squares.

Glacial Dynamics

NASA's SDP program has been beneficial to the glaciological research program at the Geophysical Institute of the University of Alaska Fairbanks. Multi-year changes in surface elevations on glaciers and ice sheets express the integrated effect of changes in flow and mass balance. Elevation changes are thus a direct measure of glacier dynamics and of the amount of water the ice mass has contributed to rising sea levels during the measurement interval. The accuracy of the DigitalGlobe/Intermap STAR-3*i* DEM of Bagley Ice Valley would have been difficult to obtain in any other way, and it has enabled researchers to estimate the spatial distribution of elevation changes on this large ice field since the early 1970s, when aerial photography was used to derive the USGS topographic maps and DEMs of this region. The result will be a unique map-plane view of the distribution of elevation changes on Bagley Ice Valley (**Figure 17**) that will be an important complement to the program of small-aircraft laser altimeter measurements on glaciers which is also being carried out at the Geophysical Institute NASA's SDP program should also play an important role in future research; acquisition of an additional Intermap GT-3 DEM of Malaspina Glacier (also in the St. Elias Range) has been approved. Malaspina is an immense piedmont glacier on the Gulf of Alaska coast that appears to be rapidly thinning because of climatic warming.—call PI

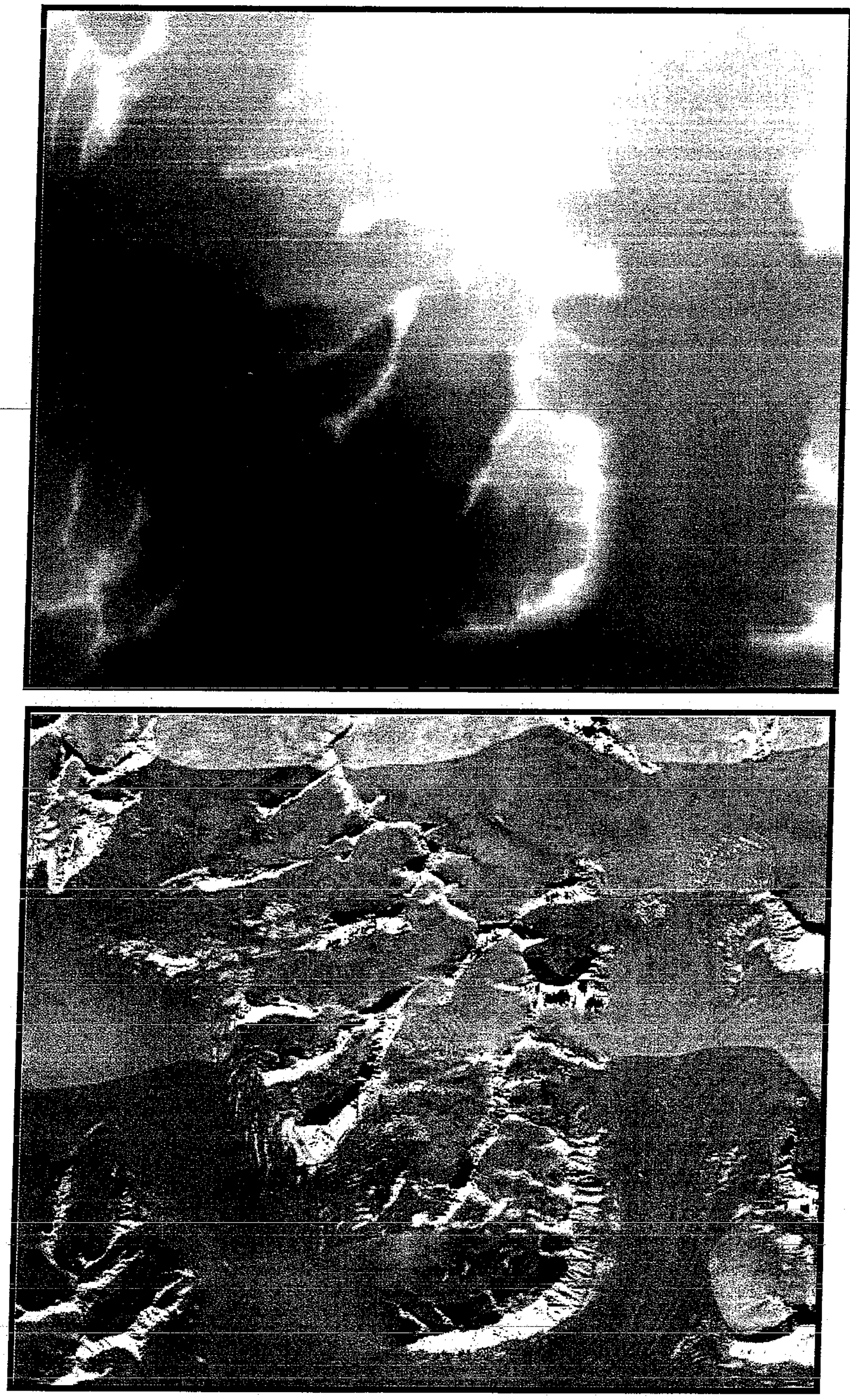


Figure 17. DigitalGlobe/Intermap STAR-3*i* digital elevation model and orthorectified image over Bagley Ice Valley.

3.2.3 Positive Systems

Positive Systems ADAR 5500 data served as a model for future high spatial resolution, space-based, multispectral systems (e.g. IKONOS). Examples of how Positive Systems data have been used include the study of watershed modeling in Yellowstone National Park, precision agriculture applications in North Dakota, the study of land cover and land use in the Washington D.C. area, and helping to visualize archaeological dig sites.

Watershed Analysis

The NASA-Montana State University (MSU) TechLink Center in Bozeman, Montana, is a NASA-funded technology transfer and commercialization center. The center receives its principle funding from NASA's ESE. The NASA-MSU TechLink's mission is to enable the availability of NASA-developed technology and resources, including the acquisition of remotely sensed data through NASA's SDP for a variety of applications for natural-resource-based and technology-based industries. Remotely sensed data adds an innovative way to measure environmental factors and is helping to streamline a variety of resource management operations. Remotely sensed data has been used for ecosystem analysis and for monitoring stream and riparian areas to help understand long-term changes.

One of the most daunting challenges facing Land Cover/Land Use Change research is developing scientifically valid indicators for monitoring ecosystem integrity at a regional scale. One method is to study streams and riparian areas to develop an effective methodology that indicates the ecological integrity of associated watersheds. Streams and riparian areas are the accumulation zones of environmental disturbances that occur through their watershed. Eroded sediments, from a variety of environmental factors, profoundly affect them. These disturbances introduce significant changes in stream sediment loads, morphology and riparian vegetation. However, streams and riparian areas have been ignored by remote sensing researchers because of the relatively low spatial and spectral resolution systems that have been available in the past; these are not conducive to successful analysis of these types of ecological areas. However, finer-scale imaging, like ADAR 5500 imagery provided by Positive Systems, made available through NASA's SDP prior to the launch of IKONOS, made a breakthrough in the utility of remote sensing technology for both scientific and commercial applications for stream and riparian study.

TheYellowstone National Park provided a unique environment for the MSU study because the factors that affect stream morphology and riparian habitat are representative of those impacting watersheds and degrading streams throughout the western United States and in many mountainous environments worldwide. The ADAR 5500 datasets (**Figure 18**) were valuable to this project 1) as a coordinate base for co-registering other remote sensing data (because the data are georeferenced, have many visual tie points, and high resolution (0.8 meter), 2) in field validation of classification of Landsat data of Yellowstone Park and the surrounding region, and 3)in enabling the long-term evaluation of changes in floodplains and riparian vegetation in the Yellowstone Park region. The data allows researchers to explore a wide range of applications involving land use, land cover, terrain modeling, and improved estimates of plant biomass. The ADAR 5500 was successful in providing a map for current work and future change detection as well as the basis for a spatial model to predict future impacts.

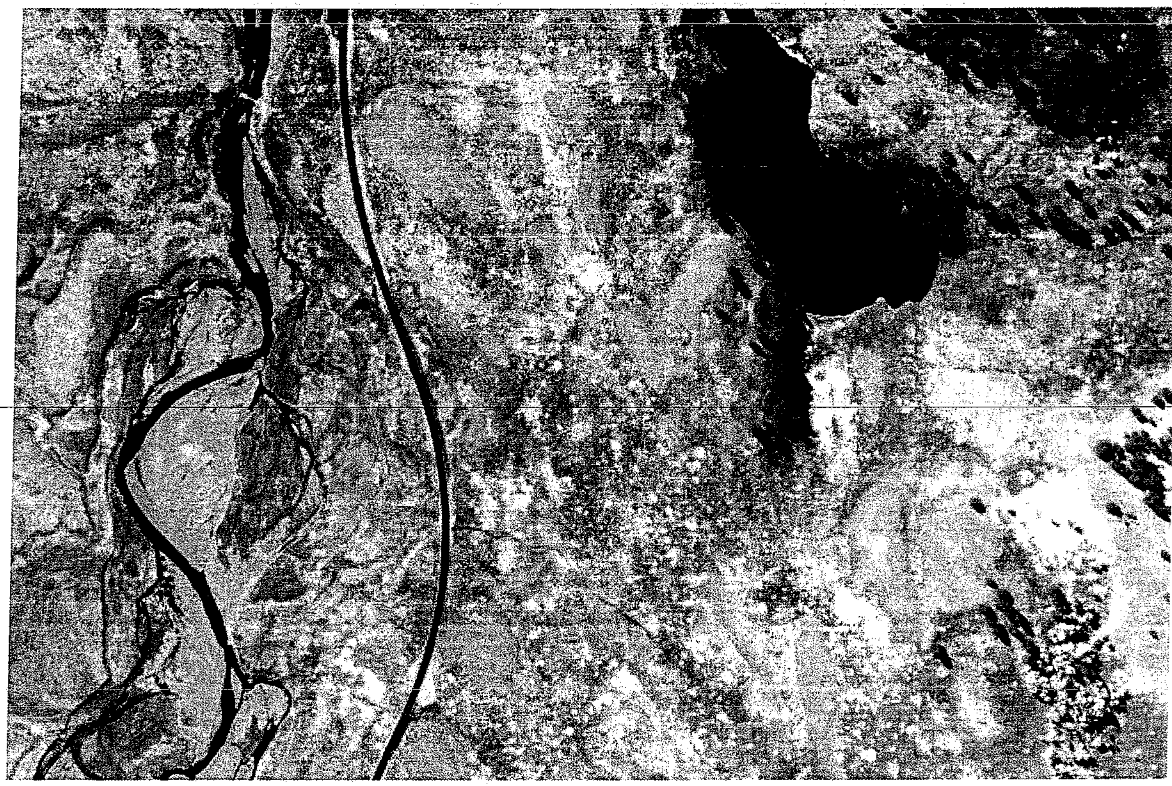


Figure 18. Positive Systems ADAR 5500 imagery used for watershed analysis in Yellowstone National Park.

Agriculture

The Upper Midwest Aerospace Consortium (http://www.geoplace.com/gw/2000/0200/0200nws.asp) used Positive Systems ADAR 5500 imagery to show the benefits of high-spatial-resolution remote sensing multispectral data to the sugar beet farmers in St. Thomas Township, North Dakota. The data collected provided the end users a first-time opportunity to receive high-resolution imagery, and use this imagery to extract information on the prevailing condition in their fields. Farmers obtained information, including the identification of stress areas caused by wind damage, crops damaged by inundation, fertilizer skips, cultivator blights, planter skips, fungicide trials, and lodging. **Figure 19** shows the detail obtainable from ADAR 5500 imagery. The infrared channel is particularly useful in detecting crop stress *before* it becomes visible to the human eye, so data collected can provide detailed information regarding early signs of crop stress; early identification of crop stress can help farmers take corrective measures. Smaller anomalies that could not be noticed on the ground could be easily identified on the imagery, helping to improve planting and management practices. Using SDP data, the consortium demonstrated that remote sensing data could reduce farmers' costs for soil surveys and fertilizer applications.

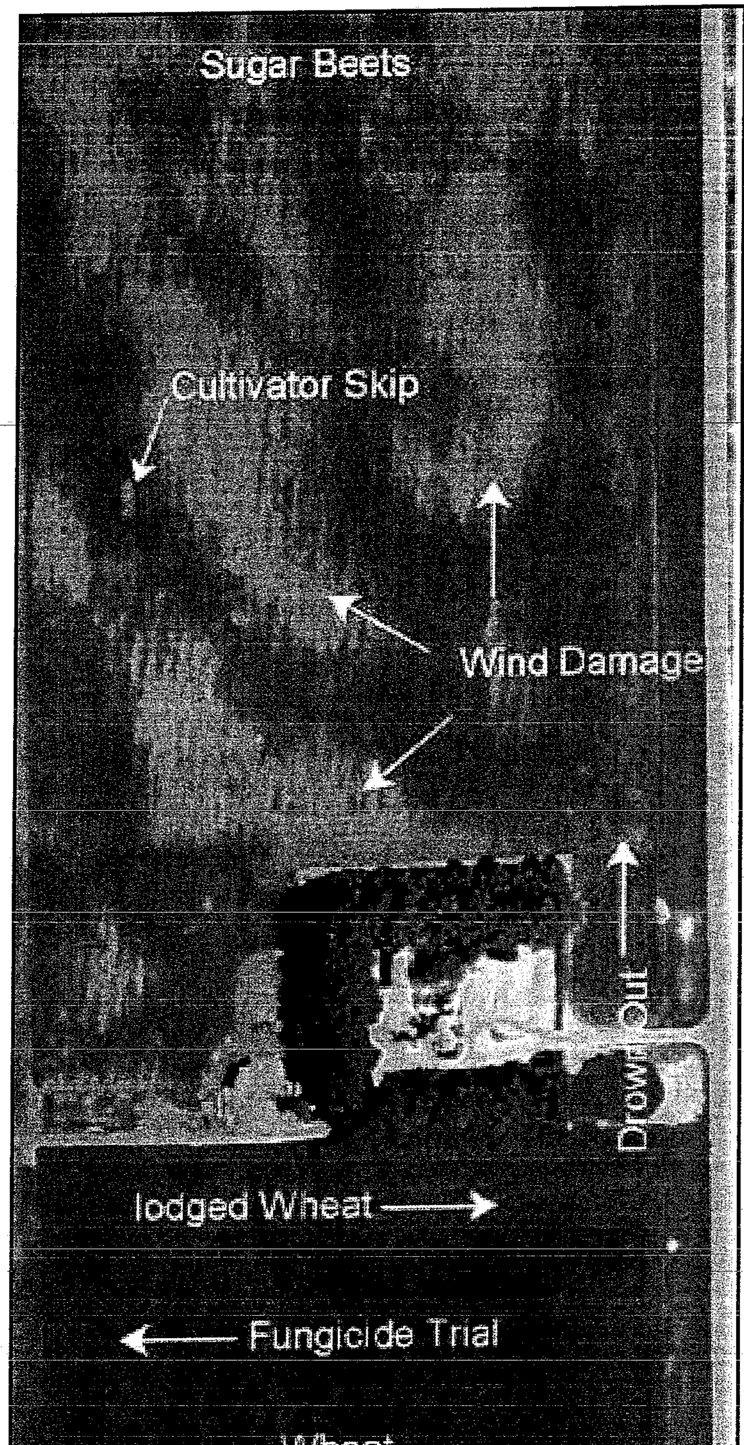


Figure 19. Positive Systems ADAR 5500 color composite showing fine details required by sugar beet farmers for improved farm management.

Environmental and Urban Landscape Monitoring

The Mid-Atlantic Regional Earth Science Application Center (RESAC) used ADAR 5500 multispectral data to examine and monitor the environmental status of land use/land cover in the Washington DC/Baltimore, Maryland, corridor. One of the goals of the Mid-Atlantic RESAC team is to develop maps and models to monitor the effects of urban growth and to predict its future direction. This information is used to assist urban planners and to help devise strategies to mitigate the undesirable effects of urban sprawl. Data received by the Mid-Atlantic RESAC through the SDP has been used to help resolve scaling issues associated with coarser-scale imagery (e.g., Landsat TM) previously used for monitoring urban landscapes. The higher resolution ADAR 5500 imagery has aided urban planners by providing a clearer understanding of city growth and has enabled a more efficient and timely study of the effects of urban sprawl on the surrounding landscape. An example of the imagery used is shown in **Figure 20**.

Figure 20. Positive Systems ADAR 5500 imagery used for characterizing and monitoring environmental status of the Washington DC-Baltimore, Maryland, corridor.

Native American Archaeology

NASA SSC research scientists have used ADAR 5500 images provided by the SDP in archeological applications. ADAR images were used for airborne visualization of a known and extensively studied prehistoric Native American archaeological site(**Figure 21**). These images were compared to field survey data as part of research into the use of multisensor imaging in archaeology The high-spatial-resolution, multispectral images collected over bare ground revealed a series of linear features very near the location of the principal mounds both at the Parchman and Hollywood sites, which are located in agricultural fields in Mississippi. After analyzing the imagery, NASA and the University of Mississippi conducted field tests at these sites utilizing a variety of geophysical surveying techniques. The field survey data supported the initial findings derived from the airborne digital imagery. At least four buried prehistoric houses at Hollywood and two at Parchman were clearly delineated by the ground truth teams and matched the location and orientation partly visible in the ADAR imagery.

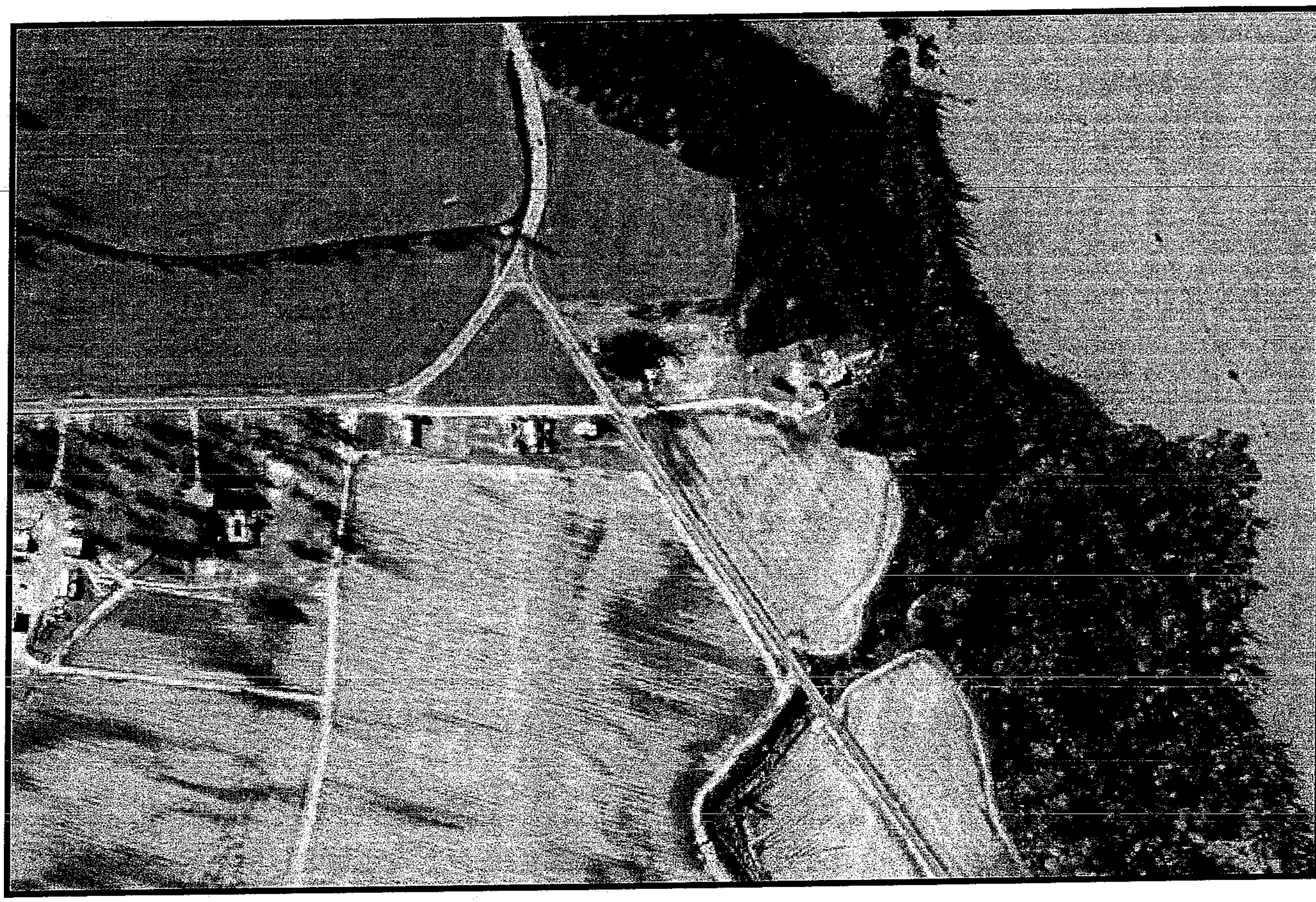


Figure 21. Positive Systems ADAR 5500 image captured over an archeological study area in Hollywood, Mississippi, in December 1999.

3.2.4 Space Imaging

Because the IKONOS spacecraft provided high spatial resolution data from an orbiting platform, Space Imaging data products have been extremely popular. IKONOS data has been used to bridge the gap between previously obtained remotely sensed imagery and fine-scale spatial heterogeneity on the ground. IKONOS imagery has also been used for the Large Scale Biosphere-Atmosphere (LBA) Experiment in Amazonia, to produce mapping-quality imagery of previously inaccessible island landscapes, to introduce the public to this high-spatial resolution data via the "Great Zooms" project, for sensor calibration and validation research, to observe changes in coral reef environments, aide in the study of vector-borne disease, and to perform land product validation.

Forest Inventory Changes in Amazonia

Space Imaging data was used at the Complex Systems Research Center at the University of New Hampshire, where investigators coordinated the acquisition and distribution of IKONOS imagery for use in the NASA-supported LBA Experiment in Amazonia. The LBA was designed to create new knowledge needed to understand the climatological, ecological, biogeochemical, and hydrological functioning of Amazonia, the impact of land use change on these functions, and the interactions between Amazonia and the Earth system. IKONOS data has been used to examine end-member selection and validation for large-scale remote sensing of land cover; to detect selective logging in forests (**Figure 22**); to detect secondary forests' stage, age, and pathway; to detect fine-scale land use change; to detect forest canopy gap and natural disturbance; to determine forest basal area and biomass; and to describe landscapes for aircraft campaign information. In this activity, many LBA investigators from various LBA teams requested specific IKONOS imagery. A much larger set of registered users (approved using formal data sharing guidelines) requested and downloaded data using the NASA Earth Science Information Partner (ESIP) EOS-Webster (http://www.eos-webster.sr.unh.edu/). In addition to the core LBA holdings, EOS-Webster also distributes some non-LBA NASA IKONOS imagery using the technology developed for serving LBA. These data are very popular featured items on the EOS-Webster and are actively used by many investigators. IKONOS data shows features not visible from NASA government systems; additional detail affects and improves accuracy of carbon sequestration prediction.

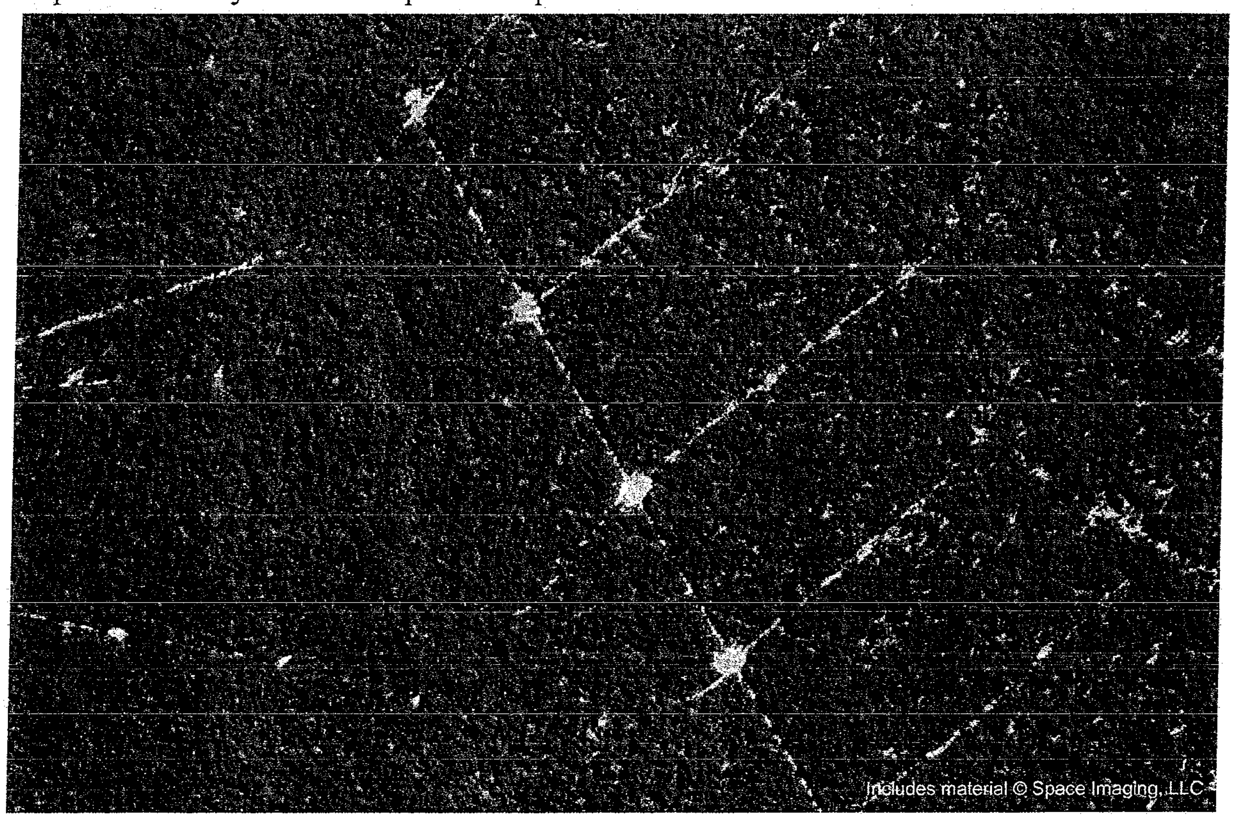


Figure 22. Space Imaging IKONOS imagery used for project titled "Large-scale Biosphere Atmosphere Experiment in Amazonia." Heterogeneity in the Amazonian forest, from selective logging, is depicted in this image.

Analyses of Sensitive Island Landscapes

NASA's Earth systems scientists have been conducting research utilizing IKONOS imaging to observe sensitive island landscapes Remotely sensed data has been uniquely effective in developing new research directions in studies about the Earth and other planets. By examining highly sensitive, previously inaccessible oceanic island landscape systems as models for global/planetary observations, valuable information correlating to a variety of landscape responses to change can be considered. Unpopulated, relatively pristine islands are ideal control experiments for quantifying the sensitivity of landscape systems to differing forcings and climate change. These responses can include and may not be limited to coastline changes associated with rapid erosion, volcanic precipitate effects, landscape response to severe coastline storm surges, marine terracing due to island subsidence or sea level effects, and previously undocumented effects of ice accumulation. Through the SDP, over one dozen IKONOS datasets have been acquired, from late 2000 to the present (**Figure 23**). This unique observational data offers promise for isolating key "sensitivity" variables in Earth science disciplines, and offers a mechanism for development of response models that could be extended to more complex, continental region. Without the SDP imagery, the ability to observe and measure changing features would not have been possible. The value of the SDP IKONOS imagery in these studies lies not only in direct scientific observations of these remote and sometimes inaccessible locations but also in providing cost-effective approaches for directing field observations and for suggesting additional remote-sensing-based experiments.

This application has also been directed to field analogue studies in support of future Mars exploration. NASA's SDP IKONOS imagery has been used to study landscapes on extremely remote locations on Earth to develop prospective studies on Mars. This study has influenced NASA's selection of a sub-meter imaging system for the Mars Reconnaissance Orbiter, scheduled for launch in 2005.

Includes material © Space Imaging, LLC

Figure 23. Space Imaging IKONOS imagery of Salar Grande evaporates and sediments (upper); IKONOS imagery of Surtsey, Iceland, layers and gullies (lower).

Visualizing Imagery at Varying Scales

SDP data acquired for the Landsat Project Science Office were used as part of the "Great Zoom" concept. The "Great Zooms" short sequences used MODIS, Landsat 7, and IKONOS data to create the illusion of "zooming in" to a particular location on Earth. The viewer is given a sense that a camera held high above the Earth, is rushing towards the surface at what would appear to be an impossible speed, passing through layers of atmosphere, and then suddenly stopping and floating in a virtual space just above the ground. The Science Visualization Studio at Goddard Space Flight Center rendered the zoom sequences. An example of several IKONOS scenes from the index of 72 "Great Zooms" (http://svs.gsfc.nasa.gov/search/Animationseries/GreatZooms.html), "Great Zoom into New York, NY: The World Trade Center," is seen in **Figure 24**. Many of the zooms have been shown around the country and have enjoyed much popularity and positive press. The vast majority of these scenes were released for Earth Day 2001 to highlight the ability of satellite imagery to document anthropogenic change. The Great Zooms introduced the public to an array of remotely sensed data, to the concept of various spatial resolutions, and to the idea of data fusion. The IKONOS data acquired through the SDP were essential to these zooms because they offered the highest resolution data contained in the zoom sequences.

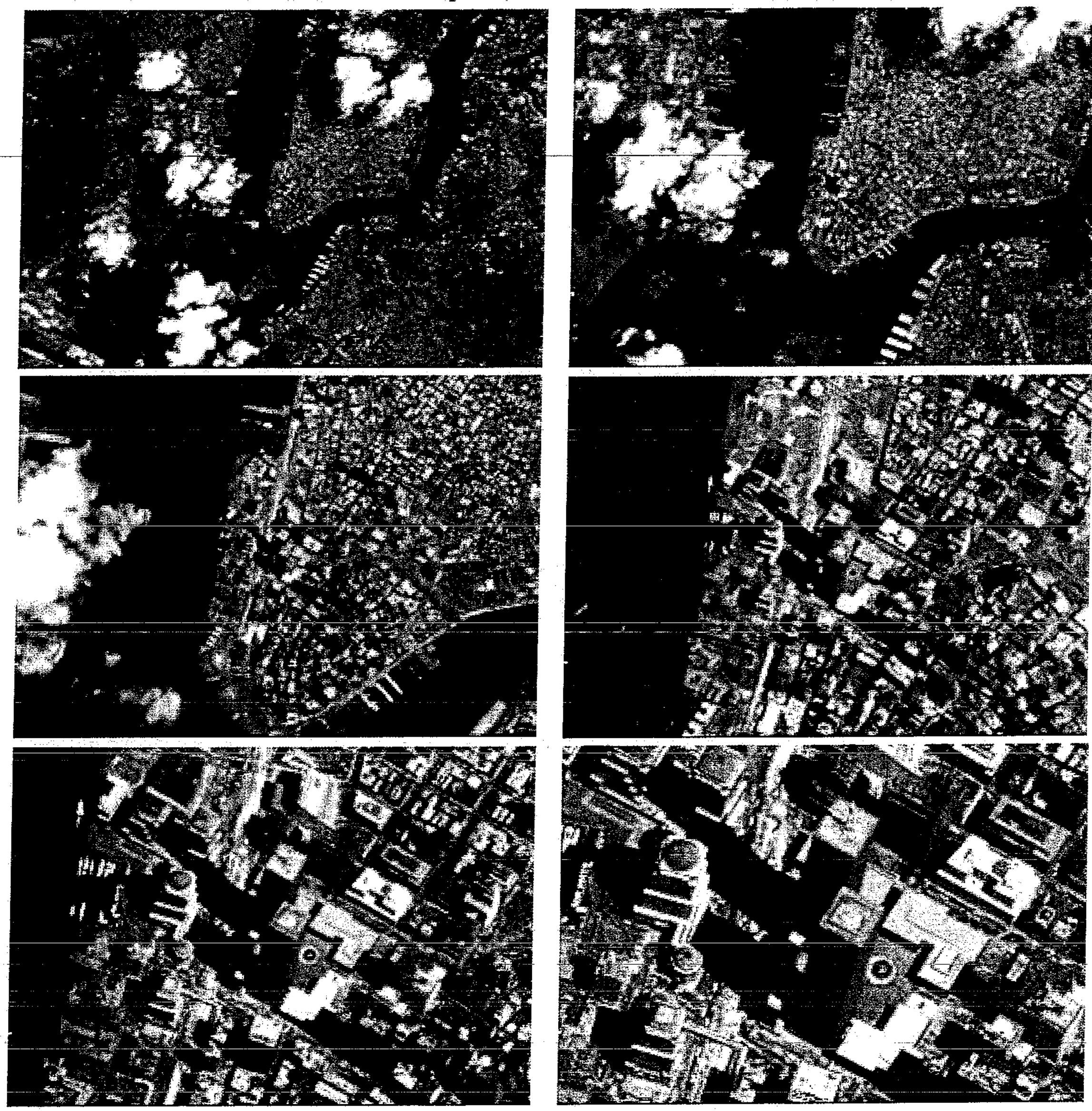


Figure 24. Several Space Imaging IKONOS scenes from the index of 72 Great Zooms, "Great Zoom into New York, NY: The World Trade Center."

Sensor Verification/Validation

In-flight radiometric calibration of satellite sensors relies on both ground-based and airborne measurements of well-understood test sites at the time of sensor overpass, combined with an understanding of atmospheric models to predict the radiance at the sensor. These predicted radiances are compared with those reported by the sensor to evaluate the sensor's performance. When these approaches are applied to multiple sensors viewing the same target, not necessarily at the same time, these instruments can be cross-compared with better precision.

The IKONOS imagery acquired through NASA's SDP was used to examine the accuracy of vicarious, radiometric calibrations for NASA's coarser resolution systems. This superior spatial resolution enabled a better understanding of both field validation approaches, and the accuracy limits that can be expected.

Using IKONOS imagery, investigators at the University of Arizona's Remote Sesning Group developed techniques that allow the cross-comparison of terrestrial imagers to examine biases between these sensors (ASTER, MODIS, Enhanced Thematic Mapper Plus (ETM+), Sea-Viewing Wide Field-of-View Sensor (SeaWiFS), Advanced Land Imager (ALI), and Hyperion), and discern differences between them as small as 2%. This was possible because the high-resolution IKONOS imagery has shown that the primary source of uncertainty in the cross-comparison of imaging sensors is surface bi-directional reflectance effects. Utilization of this information showed that the uncertainties due to spatial heterogeneity of a test site and band-to-band differences can be readily minimized; this allows accurate registration and scaling of poorer resolution sensors regardless of the site uniformity. Therefore, the imagery enabled the separation of the spatial registration effects from the other effects. This would not have been possible without the high-quality, high-resolution imagery that is provided by IKONOS. The order of magnitude difference between IKONOS and ETM+ enabled both a direct calibration of sensors and a cross-comparison. This understanding is important for application in future climate studies that will rely on the melding of data sets of varying spatial and spectral resolutions.

Coastal Reef Change Detection

NASA's ESE funded the Institute for Marine Remote Sensing (IMaRS) of the College of Marine Science located at the University of South Florida (USF) in St. Petersburg, Florida, to create an inventory of the world's coral reefs. This effort included studying and mapping reefs to help understand their recent and rapid deterioration. The ultimate objective of this effort is to use remote sensing to help provide a better understanding of changes occurring in coral reef communities and the subsequent effects upon the world's oceans.

With IKONOS SDP imagery, IMaRS was able to characterize and map coral reef ecosystems at scales that were not possible with previous field mapping techniques because of the excessive costs and the near impossibility of physically locating in the field and subsequently accessing the world's abundant and sometimes remote coral reefs (**Error! Reference source not found.**).

The IKONOS data provided through NASA's SDP was utilized for several studies. One use was direct comparison to historic aerial photography to study changes occurring on the reef environment over time. A key aspect is the comparison of results throughout coral reef biogeographic regions to obtain a global view of the potential of IKONOS for coral reef habitat mapping. All datasets quantified in a consistent fashion the decline in coral cover, thus validating the use of remote sensing techniques in coral reef change detection studies (Palandro et al. 2003, Palandro et al. in press).

IKONOS performances were also compared with other sensors such as ETM+, Satellite Probatoire d'Observation de la Terre (SPOT), ASTER and the MODIS/ASTER airborne simulator (MASTER) (Mumby and Edwards 2002, Andréfouët et al. in press, Capolsini et al. in press).

Several IKONOS images were also used to map and estimate the biomass of invasive brown algae on Polynesian reefs, providing key information to plan the harvesting of these algae for biotechnological applications (cosmetics) (Andréfouët et al.in press). The processing chain of IKONOS images acquired on aquatic environments were improved by implementing and testing an algorithm to remove sea surface noise frequent on IKONOS data (Hochberg et al. 2003). Additionally, IKONOS data are currently used for coral reef international research projects in the Bahamas, the Florida Keys, Australia and French Polynesia. Involved institutions include University of Puerto-Rico, Western Washington University, University of South Florida, University of Queensland (Australia), and University of French Polynesia (France). SDP provided support for enhancing the design of tools used for coral reef science and management worldwide and contributed to the education programs of several international institutions. The amount of research and work summarized would not have been possible without this interface between commercial providers and the scientific community.

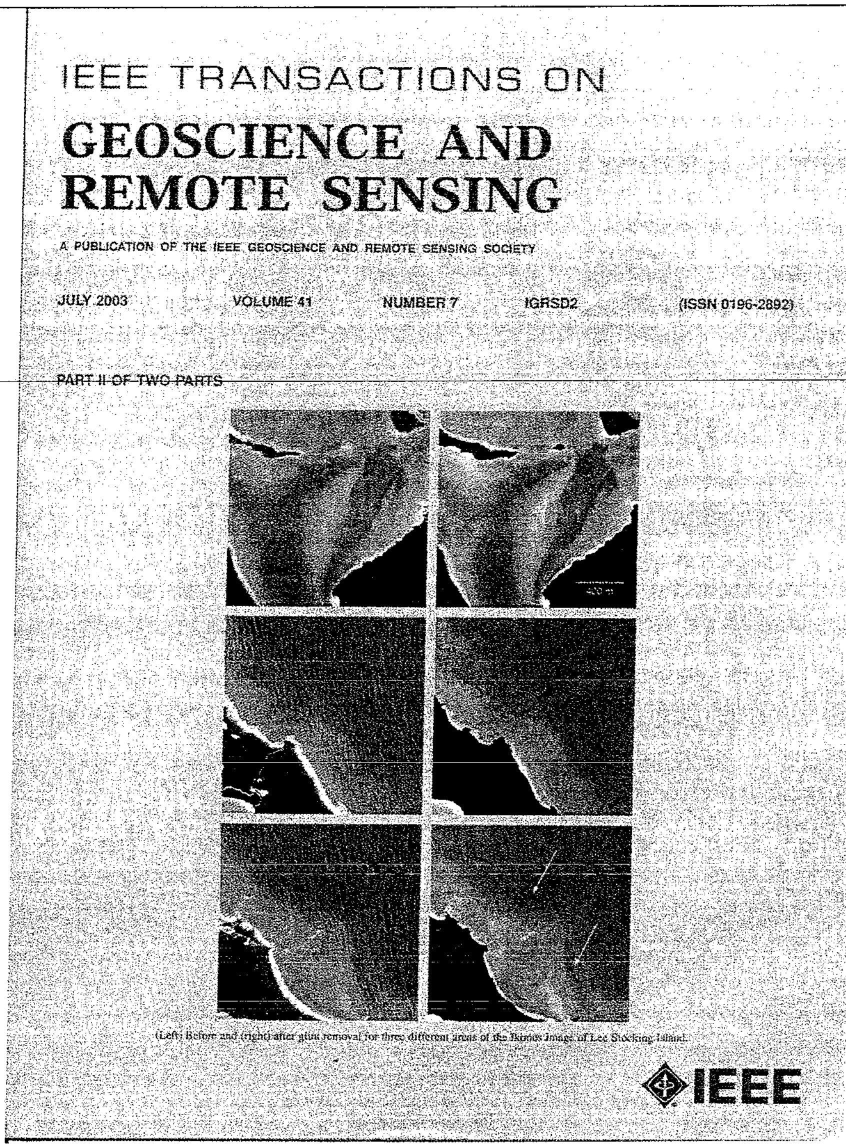


Figure 25. Shown above is Space Imaging imagery included as the cover story in the July 2003 issueof *IEEE Transactions on Geoscience and Remote Sensing,* Vol. 41, NO.7. The article is entitled "Sea Surface Correction of High Spatial Resolution Ikonos Images to Improve Bottom Mapping in New-Shore Environments" by E.J. Hochber, S. Andréfouët, and M.R. Tyler.

EOS Land Validation

The MODIS sensors on NASA's EOS Terra and Aqua satellites plays a vital role in the development of products that are used for measuring and monitoring land surface variables. These variables include land cover, leaf area index, fraction absorbed photosynthetic active radiation, and net primary production products. Validation of these products is crucial for assessing their accuracy for the scientific user community and for providing feedback to improve data processing algorithms. The MODIS land discipline team (MODLAND) is responsible for statistical and geostatistical analysis on multiple satellite sensor products.

As part of the MODLAND validation plan, key study sites were identified. These evolved into the MODLAND Validation Core Site network. One of the main objectives for the core sites is to have consistent data sets available for each of the globally distributed sites. There is also the objective of providing very high-resolution imagery over the sites to support georeferencing, field reconnaissance, more coarse resolution image interpretation, and exploration of scales of spatial variation in biophysical properties of the landscape-all of which are important considerations for validation studies.

Only until recently has the Earth science community been able to meet the requirements of globally consistent imagery and very-high resolution data. The SDP IKONOS imagery provided unique and beneficial imagery over the EOS Land Validation Core Sites. Without this high-resolution imagery, the only other option for such data would have been airborne imagery. Airborne image acquisition for several remote core sites is either cot-prohibitive, too time consuming, unsafe, or logistically difficult or impossible. In light of these considerations, NASA's investment in high-resolution imagery through the SDP supplied the EOS Land Validation Core Sites with unique, globally-consistent, critical validation data sets at a reasonable cost.

The MODLAND Core Validation Sites are also associated with "BigFoot" project study sites. Each BiFoot site is approximately 5 x 5 km in size, and includes a CO_2 flux tower and an associated science program that involves carbon cycling, water vapor, or energy exchange. The BigFoot project evaluates ground measurements, IKONOS data acquired through NASA's SDP, and ecosystem process models at different study sites. Using this combination of *in situ* ecological data and remotely sensed data, the BigFoot project explores validation protocols and scaling issues to improve understanding of several MODLAND products.

IKONOS images were useful for planning routes to collect field measurements, because some BigFoot sites are in remote, locations. Land cover field measurements and observations, are often directly related to Landsat imagery; however, complex spatial patterns existing on the landscape often limit interpretations. SDP imagery was most comprehensively used as an aid in developing a field sampling strategy. The extent to which imagery could be used as a surrogate for field measurements as well as determining the scale of variation in biophysical properties on a landscape were considered when using the imagery. IKONOS imagery was used to determine whether there were variation scales finer than that of 25 m, and to track general spatial patterns of a biophysical variable. IKONOS imagery degraded from 4 m to 512 m (top) and corresponding semivariograms calculated from that imagery at Sevilleta National Wildlife Refuge (bottom) could be compared in (**Figure 26**). It was observed that Landsat data could be used to determine the scale of variation in biophysical properties of this landscape; however, this was only confirmed by using finer resolution IKONOS data.

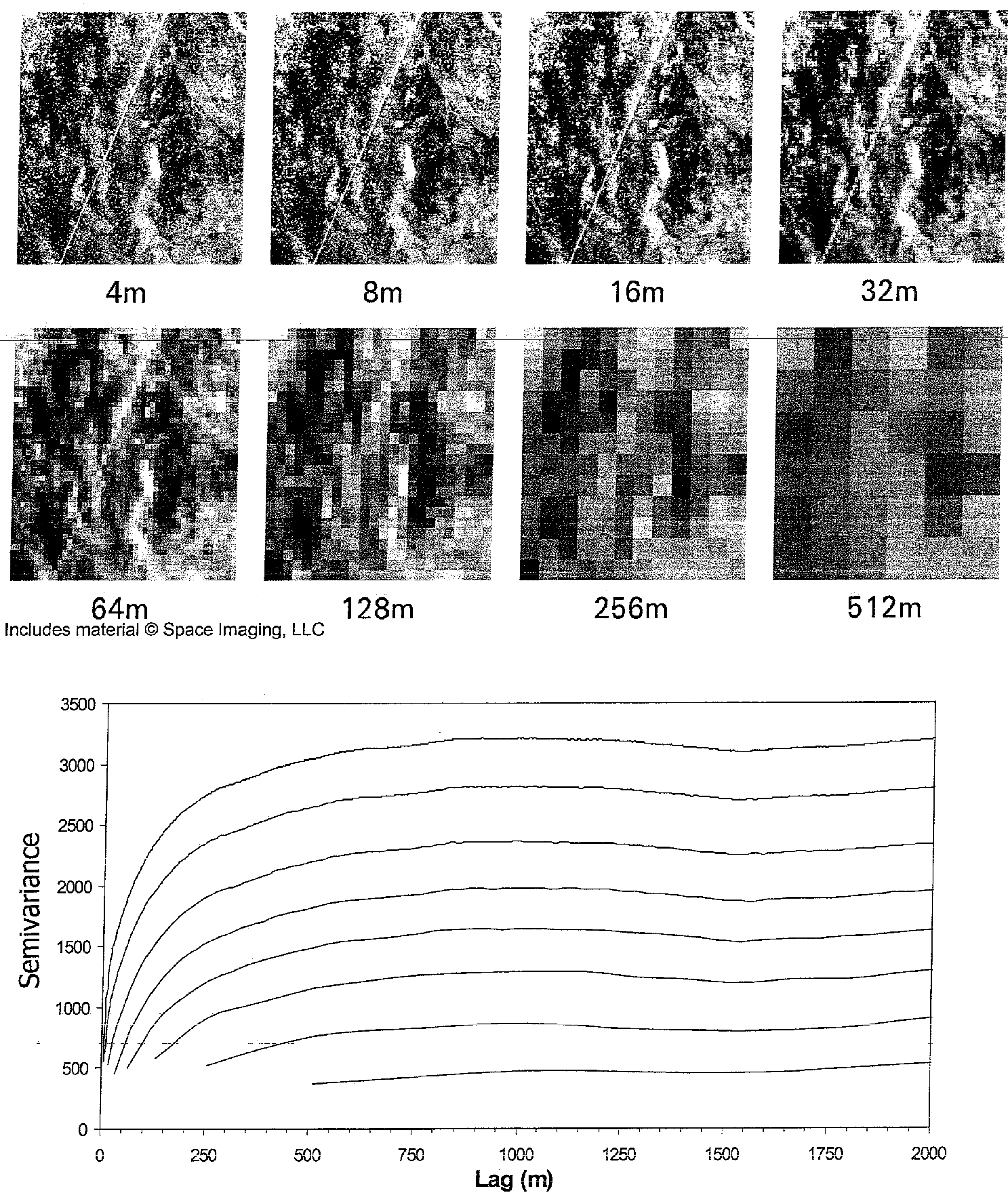
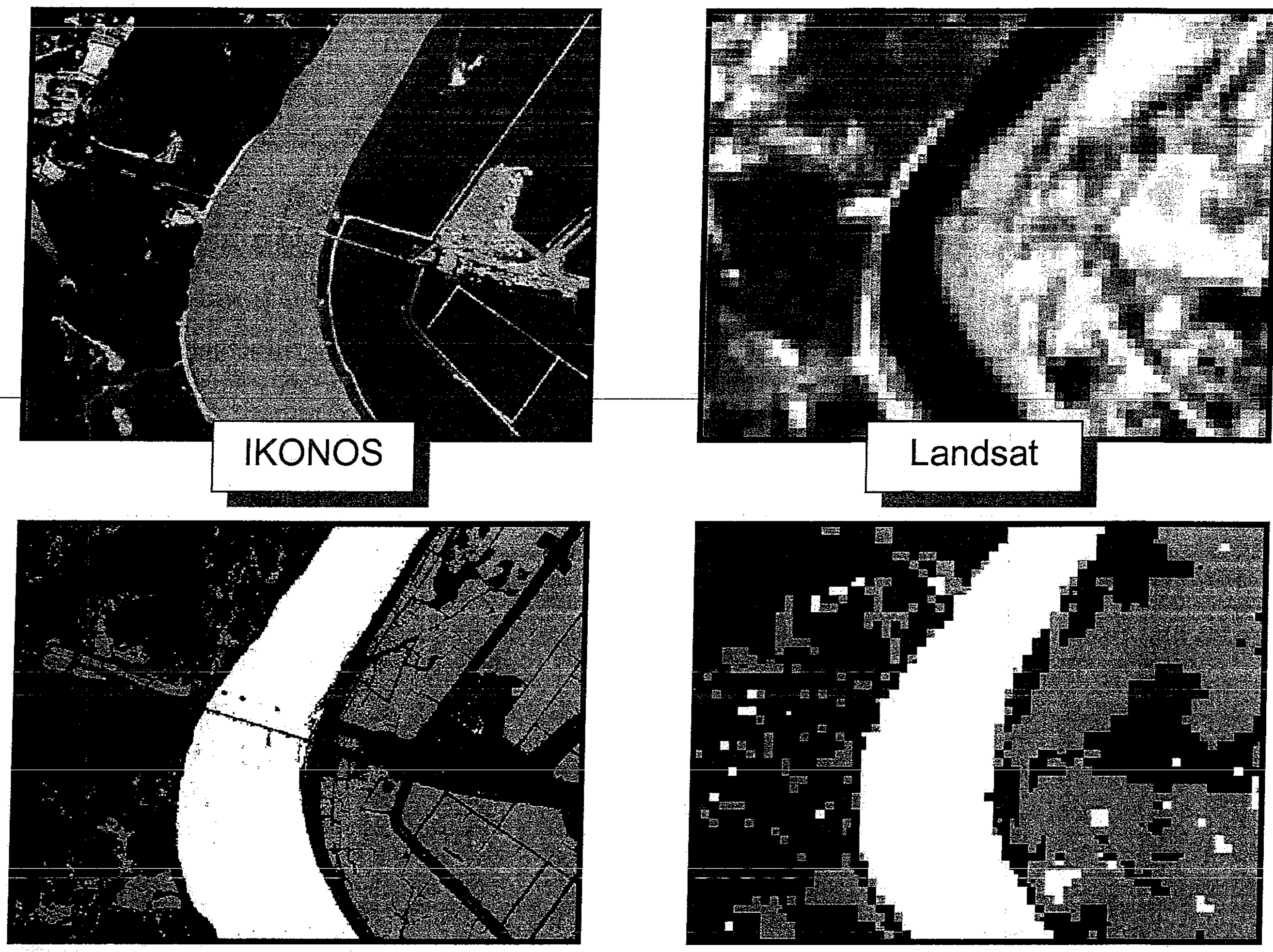


Figure 26. First principal component of 4-band Space Imaging IKONOS image over a 3 km by 3 km area of the Sevilleta National Wildlife Refuge in New Mexico (A "BigFoot" study site) spatially aggregated from 4m to 512m (top). Semivariograms were calculated from the imagery at each spatial resolution or grain size (bottom).

Malaria Prevention

NASA's Earth Science and Public Health program has been collaborating with the Uniformed Services University of the Health Sciences (USUHS) in Bethesda, Maryland, to examine the utilization of GIS techniques and remote sensing data at various scales to study environmental determinants of vector-borne disease in several countries. For example, the number of cases of malaria in South Korea has tripled since the 1960s. The close proximity of buildings, military posts, and other housing projects to rice paddies and potential mosquito breeding sites suggest that this problem will continue to grow unless these issues are addressed.

Mosquitoes and their habitats need to be studied to understand high-risk areas for disease. When discussing the endeavor of local-scale mapping of mosquito habitats, which include marshes, streams, ponds, and other land cover, high-resolution imagery could be considered an excellent tool for this task. The detailed IKONOS imagery provided information about these locations that would have been difficult to obtain in the field (**Figure 27**). Once preliminary field surveys of possible mosquito breeding sites have been mapped on a local scale, they can be used in conjunction with remotely sensed imagery to create a regional model of potential risk for malaria transmission and the necessary preventative measures can then be taken.



Includes material © Space Imaging, LLC

Figure 27. Space Imaging IKONOS and Landsat images (false color and classified) showing vector habitat and non-habitat areas. The difference in detail is due to the difference in resolution of the two images: IKONOS has 4-meter pixels and Landsat has 30-meter pixels. In the classification, river is shown in yellow, rice fields in green, irrigation ponds in red. Because irrigation ponds are small, they could not be classified on the Landsat image.

3.3 Publications

Probably the most striking evidence regarding the impact of SDP data is the number of publications and presentations that have incorporated SDP data and related results. SDP data users report having 71 articles published in, submitted to, or in preparation or review for a peer-reviewed journal. These researchers have made 198 conference presentations and have produced 25 Web products/articles, 9 reports, and 8 educational presentations. A comprehensive bibliography citing 311 references is included in Appendix D. Each reference also notes the primary investigator for the project, the NASA project title, the NASA grant number, and the specific type of remote sensing data that was utilized for the project. Of the studies represented in this reference, 31 utilized EarthSat data, 15 utilized Digital Globe data, 26 utilized Positive Systems data, and 253 utilized Space Imaging data. Examination of these references could provide additional information on a variety of specific studies and data uses. Because the nature of science research is generally long-term, many SDP projects are ongoing and may result in future publications. (update numbers)

4.0 Survey-based and Statistical Evaluation of the SPD Program

In addition to the many examples provided in section 3.0, the impact of the SDP was also evaluated using user surveys and SDP-related statistics. The focus of the evaluation included overall contribution to Earth Science Enterprise research and effectiveness of the program.

The SDP program used several mechanisms to determine the types of research benefiting from SDP data. These mechanisms provided a means to evaluate the impact of the SDP program. The SDP evaluation comprised three primary components: an e-mail survey distributed to all SDP data recipients (Appendix C), Customer Feedback Letters (Appendix B) and SDP Data Use Statistics

4.1 SDP Email Survey

An e-mail survey (shown in Appendix C) was sent to all SDP users that received SDP data. Qualified users were sent one e-mail survey regardless of the number of data requests they had submitted. Two hundred fifty two surveys were distributed to SDP customers. Recipients were requested to respond to the e-mails within six weeks from receipt. The survey requested that the SDP user supply a brief summary of the impact of the data received, including data effectiveness and the data's role in future research or application, and a list of publications/presentations in which the SDP data played a role. The users were also asked to indicate any issues (technical, administrative, or other) that precluded effective use of the data received. Nintey-three responses were received from the 252 surveys disseminated; this reflects a 37 percent response rate.

4.1.1 Data Impact

In nearly all received responses, the data provided to the researchers by the SDP was either instrumental to the research being performed or supplemented data from other sources or sensors. Fifty-five percent of the responders expressed that SDP data "complemented existing projects." Forty-seven percent of the responders indicated that the SDP data "enhanced" projects that were already in progress. Thirty-four percent of the responders indicated that the SDP data they received was "invaluable, crucial and/or essential for their research. Additionally, the majority of respondents (69%) provided positive comments regarding data impact, included the following:

- 13/93 researchers were "able to acquire data that would have been prohibitively expensive,"
- 11/93 users expressed a "significant decrease in time and effort required to collect spatial data."
- SDP data provided 7/93 researchers with a "cost-effective way of doing research,"
- 5/93 responders indicated that data was used in conjunction with some teaching facility
- 28/93 researchers suggested that, if available, SDP data would play a significant role in future research projects

These responses demonstrate that the SDP data seems to have had a positive impact on the research being performed.

A limited number of negative comments were also received in response to the email survey. Three survey responders claimed that the data they received had a negative impact on their work. One NASA researcher stated that "Space Imaging fell short of their advertised capabilities with respect to the product it was 'truly' able to offer." This comment was related to acquisition and delivery time and scene size. However, even with these misconceptions, this data was used for a separate project, and the work has been currently submitted for publication in a peer-reviewed journal. Additionally, two researchers were "not able to use the data as they intended." One researcher had hoped to use the digital elevation map derived by STAR 3i/intermap for estimating ice slopes and roughness for the Bagley Ice Valley, for use in ICESat simulation studies; unfortunately the horizontal and vertical resolution of the STAR 3i was not sufficient for this application. Airborne laser measurements instead of radar measurements were requested, and perhaps this was the problem. However, this data was useful for another researcher who is involved with ice surface studies. For another researcher, scenes were ordered in fall of 1999, and not received until June 2000. By the time the data was received, project emphasis and interests had shifted. Fortunately, another department was able to use the scenes in several separate application projects. Nine other researchers also mentioned that due to the extent of time it took to receive the data, the images could not be used as expected. Only two researchers had problems regarding the data rights restrictions, and only one researcher had a problem with the cloud cover on their point of interest in their images.

4.1.2 Issues

Seventy-five percent of the responders to the email surveys indicated that no issues precluded the effective use of the SDP data they received. The majority of the other 25 percent of the users stated that the amount of time it took to receive the SDP data (i.e., data acquisition to data receipt) hindered effective use of the data. It should be noted that, many of these latter respondents were involved in precision agriculture studies. Crop conditions can change rapidly during the peak time of the growing season, and producers typically need to make management decisions (e.g., pesticide or nutrient applications) within 3-5 days following assessment of the crop's condition. Therefore, to maximize the utility of the imagery for making management decisions, shorter intervals between data collection and data receipt is paramount.

Another issue described by a small number of respondents was the data rights restrictions placed on the data. Several researchers felt that the data could be used more effectively if the data rights agreements did not prevent data transfer. Copyright restrictions prevented researchers from sharing scenes with other collaborators and in effect reduced the potential overall impact of the data.

4.2 Customer Feedback Letter

Responses to Customer Feedback Letters (Appendix B), which were distributed with each SDP data shipment, were also compiled and evaluated to help assess customer satisfaction. In the Customer Feedback Letter, the data recipient was asked to rate the quality of the data received, the experience with the individual vendors, the experience with the overall SDP process, the usefulness of the data, the effect the Data Rights agreement has on the utility of the data and/or ability to accomplish research objectives, and finally provide comments regarding process improvements and alternate data types that could benefit their research. This information was maintained in a database and updated monthly to track customer satisfaction. The data recipients were also asked to provide a list of publications that have incorporated the use of SDP data. Of the 2835 data shipments distributed by the SDP, 436 feedback responses have been received, in a 15 percent customer feedback response rate. The feedback responses reflect that on a scale of 1 to 10 (10 being the best), the average quality

of the data received was rated at 8.7, the average data usefulness to the principal investigator was rated at 8.6, and the average overall experience with the SDP process was rated at 8.7. Also, the limitations of the data rights agreements on the data utility were rated on a scale from 1 (adverse effect) to 10 (no effect), and it was found that the average limitations of the data rights agreement were rated at 8.8.

4.3 SDP Statistics

SDP statistics that tracked tasking, data and users were compiled over the life of the SDP. Regarding tasking, 106 DigitalGlobe/Intermap tasking requests, 46 Positive Systems tasking requests, and 663 Space Imaging tasking requests were reviewed and approved by a science tasking committee and subsequently completed (EarthSat products do not require tasking requests; these products are requested through the SDP archive). A total of 815 tasking requests have been submitted and approved via the web site; 706 of these requests have been completed, i.e., the requested data has been acquired and distributed. 109 outstanding/rose

Figure 28 displays the current SDP archive holdings, representing the amount of data currently available in the SDP archive for each vendor. Approximately 25 terabytes (TB) of data were received from the SDP vendors and were made available for ordering from the archive by NASA researchers. To date, 1083 orders have been requested from the SDP archive, 1067 of which have been completed and shipped. It is important to note that the data requested from the SDP archive represents reuse of remote sensing imagery procured by NASA. A total of 2835 datasets have been distributed, either from the archive or to fulfill task requests, representing 31.3 TB of data shipped to science and application users through the SDP program. The geographic coverage of this data is shown in **Figure 29** and **Figure 30**. The SDP public web site also contains unrestricted, compressed EarthSat mosaics that are available for download. To date, a total of 1,939,235 mosaics have been downloaded for a total downloaded volume of 77.77 TB.

As of September 1, 2003, 665 users from the science and applications communities affiliated with NASA have registered with the SDP. Of these registered users, 361 have received SDP data. The registered SDP users can generally be categorized by the following affiliations: university personnel, other U.S. government agencies, non-university NASA contractors, NASA (exluding SSC, which is shown separately), contractors to other U.S. government agencies, internal NASA SSC, and foreign. The distribution of registered users who have ordered data is shown in **Figure 31**.

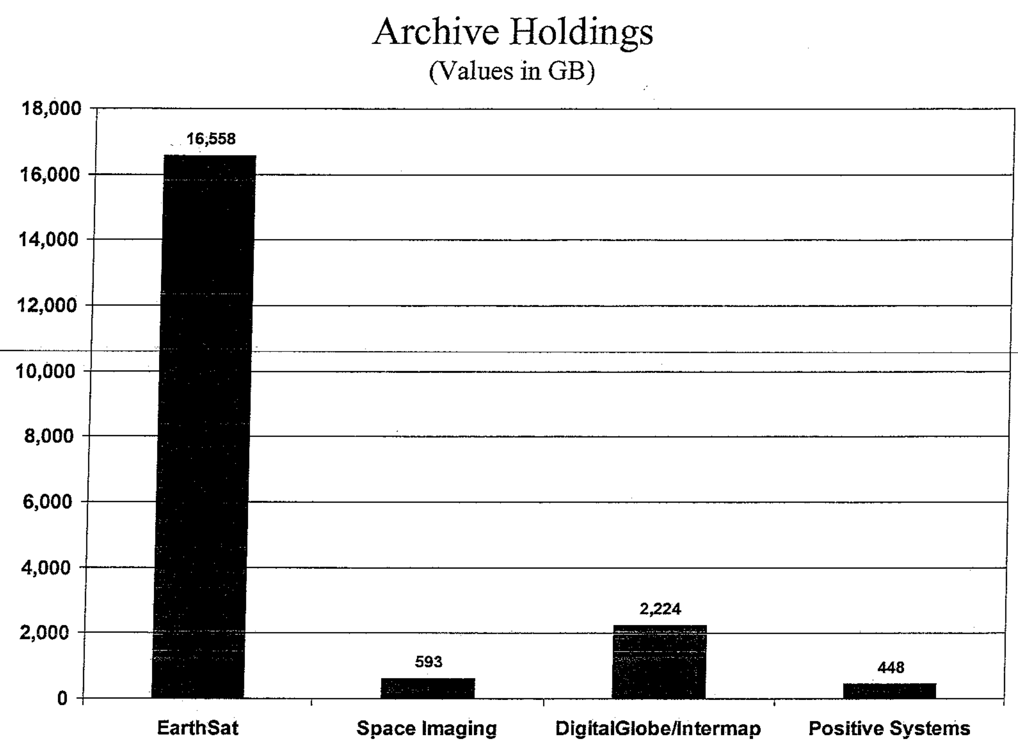


Figure 28. Amount of data currently available in the SDP archive as of September 1, 2003.

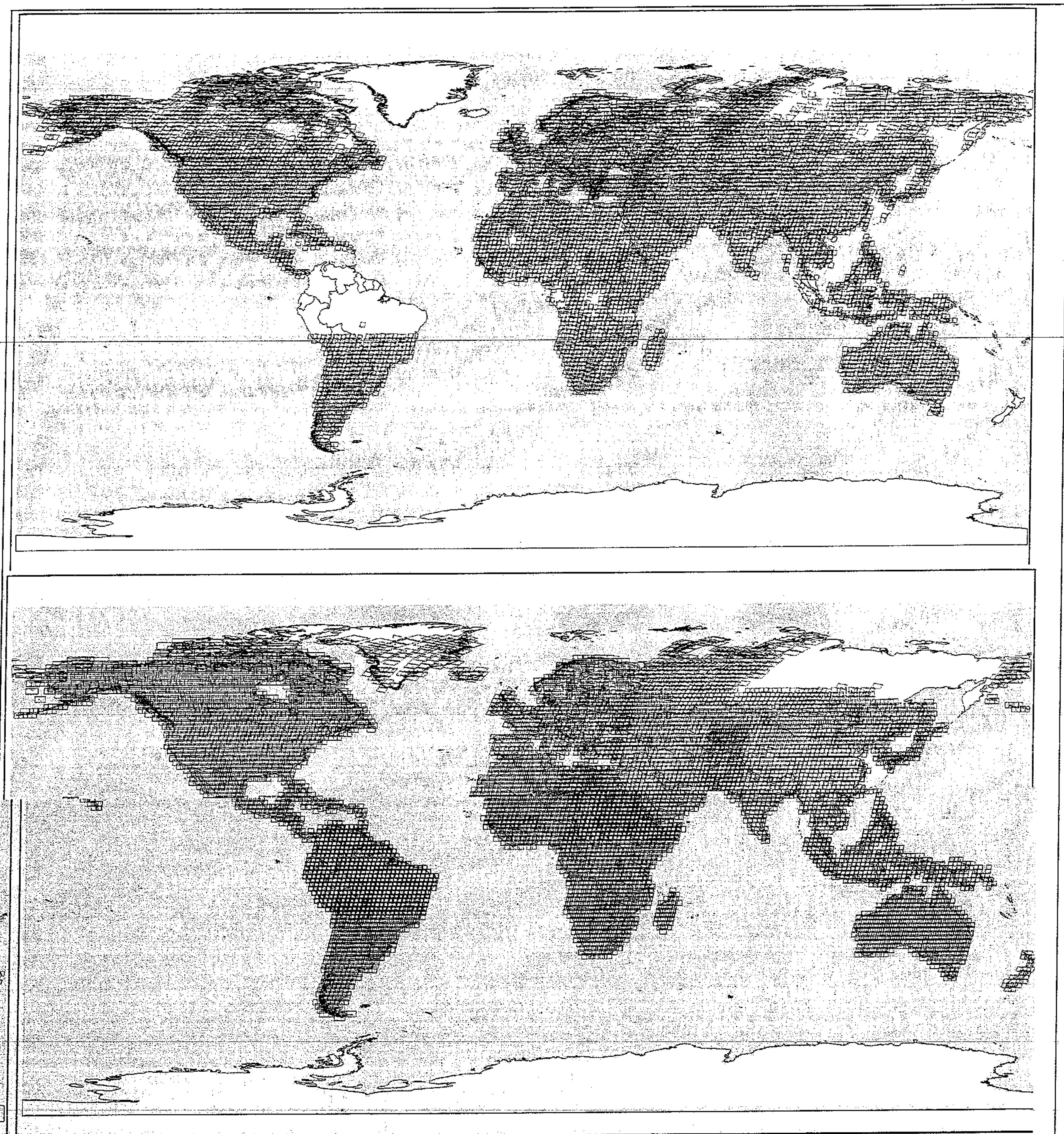


Figure 29. EarthSat Global Coverage, MSS scenes (top) and TM scenes (bottom) purchased through the SDP and available in the SDP Archive. Areas that are not covered (i.e. not green) represent areas for which MSS or TM data could not be obtained.

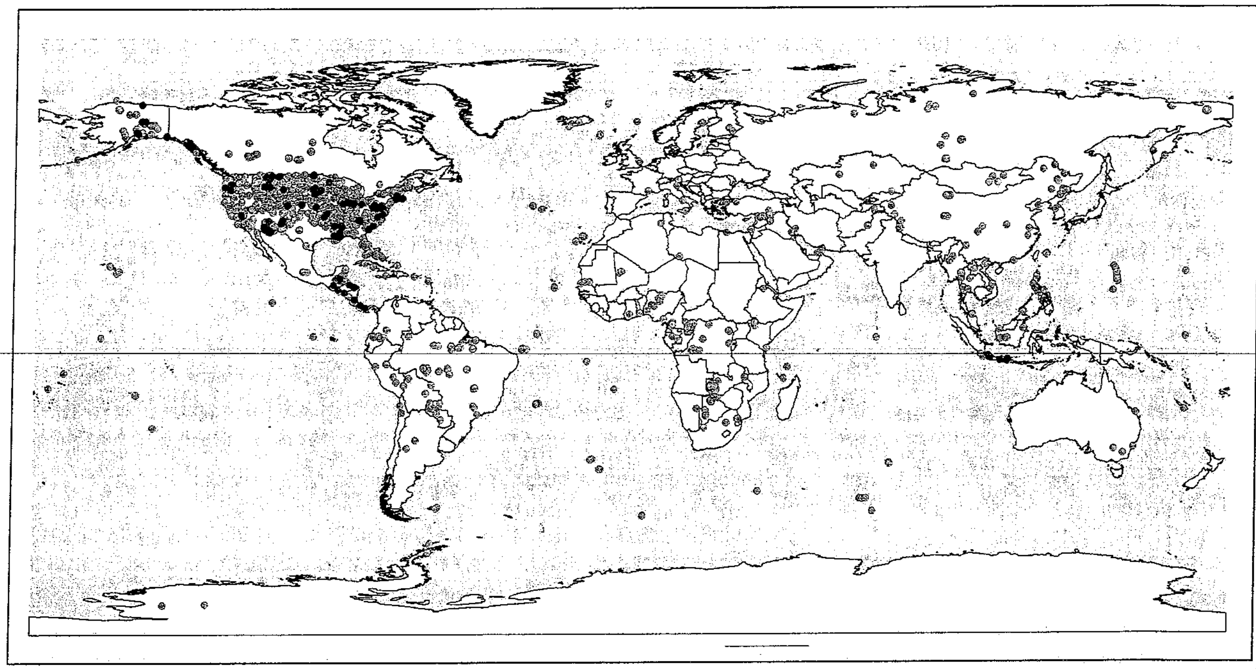


Figure 30. Locations of Space Imaging (green), Positive Systems (blue), and EarthWatch (red) tasks currently available in the SDP Image Archive (symbols are not indicative of the square kilometer area covered by aquisition).

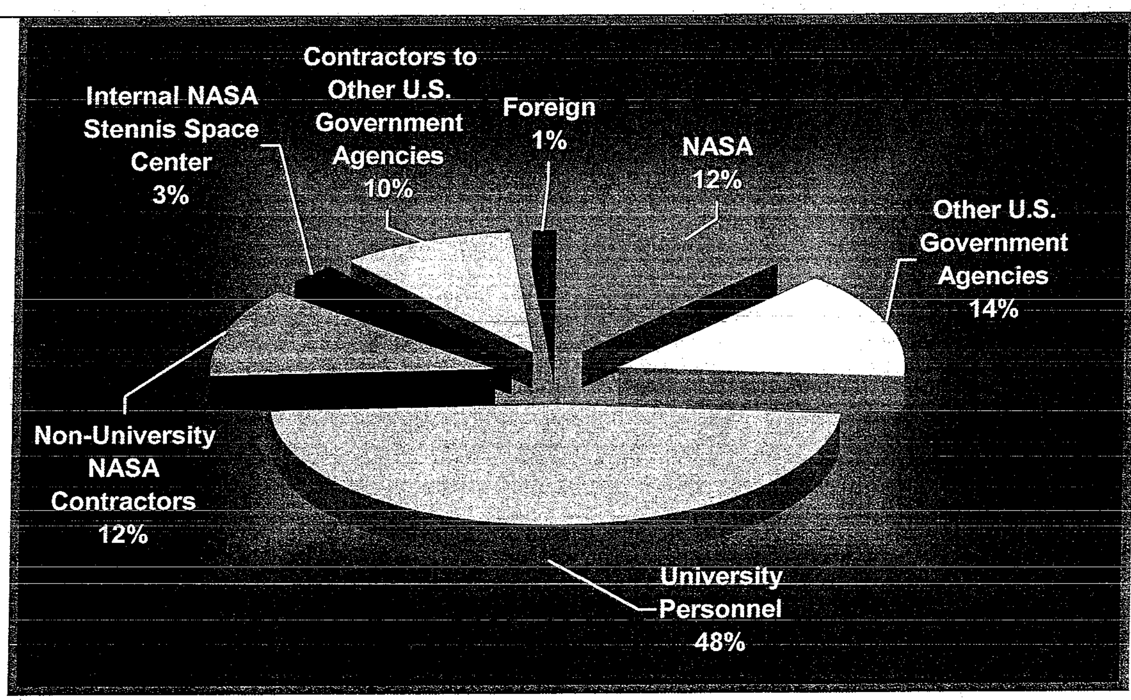


Figure 31 .This pie chart depicts a percentage breakdown of the categories of SDP users who have ordered data from the Scientific Data Purchase program.

5.0 Lessons Learned

In many ways, the SDP represented an unprecedented partnership between NASA and commercial data providers. Many of the processes employed by the SDP were developed as needed as the program grew and evolved, resulting in lessons learned by both NASA and the data providers regarding commercial data and government/vendor/researcher interaction. Several of the lessons learned within the SDP program are similar to observations and recommendations made independently by the National Research Council in its 2002 report.

5.1 Useful Data, Minimal Risk

The original goals of the SDP program were to obtain Earth science data from the private sector, and to demonstrate that industry is willing to accept a majority of the precursory financial responsibility when providing this data. These goals have been met: the commercial sector can provide data while posing minimal risk to NASA, and the data products have proven to be useful to the science community.

With each SDP dataset delivered, NASA sent the participating scientists a questionnaire regarding the data usefulness and the quality of the service provided (Customer Feedback Letter, Appendix C). With a favorable response rate, the questionnaire indicated that almost all of the scientists advocated access to commercial data. The SDP data use, which reflected the MTPE science and applications categories, showed that the majority of users classify their research as Land Cover and Land Use (Science Research Category) or Resource Management (Applications Research Category), but the data also supported a broad spectrum of other research areas.

In many cases, the commercial sector becomes the sole source of providing certain types of remotely sensed data (e.g. high spatial resolution imagery from satellite and airborne LIDAR and IFSAR). Datasets such as those available from Space Imaging's IKONOS satellite open new opportunities for validating conclusions and conjectures derived from the government's coarser spatial resolution systems and for fine-scale feature extraction and virtual ground truthing. For the first time, phenomena inferred by spectral processing of coarse-resolution data can be validated by visual inspection with this high-spatial-resolution data. The National Research Council report (2002) notes that as a result, the usefulness of the government's coarser resolution systems is increased.

Because several of NASA's SDP contracts are Indefinite Delivery-Indefinite Quantity (IDIQ) contracts that require no precursory financial investment, the government has a means for purchasing only required data. Space Imaging's SDP contract enabled the NASA to purchase IKONOS data at a fraction of the cost associated with designing, constructing, and operating an asset like IKONOS; a similar system would cost millions of dollars. In addition, the SDP has pioneered the way for other data purchases, including POAM III, Ocean Winds, QuickBird 2, and OrbView-4 Warfighter hyperspectral (NASA data purchase contract canceled due to launch failure, at no cost to the government).

A cash-on-delivery data contract for unique data, especially prior to the system being operational, does contain some risk for NASA, including the potential of not receiving the data, and return of funds to the U.S. Treasury. This was the experience with the SDP contract with AstroVision, Since the company was not able to build and launch their system prior to the end of the life of the SDP contract, the contract was canceled and the associated funds were returned to the U.S. Treasury. The funds lost to NASA were $1.35 million, or 2.7 percent of the total SDP $50 million program. This may not seem as a significant failure for an experimental program, particularly when considering that the U.S. government as a whole did not incur any loss of funds. NASA may have been able to mitigate this risk with a thorough expert review of the company's business plan during the SDP proposal evaluation process. Another possible complicating factor may have been the development of NASA's DSCVR mission, a mission to provide continuous full-disc views of the Earth from the sun-Earth libration point (1,000,000 Km from Earth). The similarity of DSCVR to the AstroVision planned observations may have affected the company's ability to secure venture capital to build their system. NASA, and other government agencies, must take care to select and design missions that are not perceived as competing with commercial systems.

While NASA did not lose any existing capability by not receiving the AstroVision data, the fields of natural hazards and disaster management research and applications were not able to benefit from this new source of Earth observation. This data source could have potentially benefited studies of hurricane development and tracking, thunderstorm development and tornado warning, fire monitoring and risk analysis, volcano event monitoring, coarse scale monitoring of flood events, and cloud mapping for prioritization of other imaging events during emergency response activities.

5.2 Maturing Industry

Commercial remote sensing is a maturing industry. Customer service and product delivery time can be erratic, and saturation of tasking over an area of interest is unpredictable. Data specifications, minimum order sizes, and acquisition windows are also variables that are still evolving. In some cases, NASA discovered that delivered products did not meet contract data specifications. Following characterization, NASA opted to accept these products if they were deemed useful to the science community, because customizing commercial products for specific needs can lead to product delivery delays. The scientific community has a wide range of requirements, and the products that could have been rejected were still found to be useful. As a result, contract data specifications were changed to reflect the data's true performance.

5.3 Characterization

Commercial data products must be highly characterized. Unlike government-owned systems, commercial providers do not typically release detailed system descriptions because of competitive and propriety concerns. Consequently, the science community largely views commercial systems as "black boxes." This is a new paradigm for the NASA scientific community, which historically has had significant insight into sensor design and operation. Also, because commercial providers and the scientific community may have different system requirements and objectives, commercial providers may not necessarily characterize systems in the manner preferred by NASA researchers, necessitating independent data characterization. NASA has provided an independent characterization of each of the SDP data provider's datasets as discussed in Section 2.2.1. The National Research Council (2002) reported that one of the most significant contributions of the government to the data purchase process has been data validation.Partnerships have been found to facilitate the characterization process significantly. NASA and the NIMA currently procure IKONOS imagery; the USGS is considering procuring IKONOS and other commercial imagery. By forming a Joint Agency for Commercial Imagery Evaluation (JACIE) team with NIMA, USGS, and several university affiliates, NASA has capitalized on the groups' mutual interests. Each JACIE agency brings different strengths to the activity. This, in turn, reduces the cost of a full evaluation by minimizing duplication of government and industry efforts. This group provides a single government interface with Space Imaging that not only characterizes the IKONOS system but also obtains system information. This JACIE verification and validation team effort has resulted in updated radiometric calibration coefficients for IKONOS data. This update reflects coefficients obtained during a vicarious calibration efforts t initiated by the JACIE team. Discussions between the JACIE team and Space Imaging led to the discovery that the IKONOS system compresses the datasets onboard the spacecraft; however, the lossy compression has had a minimal impact on the research, because the 11-bit data provides an increased dynamic range. Another discovery was that Space Imaging uses a digital image restoration technique called Modulation Transfer Function Compensation (MTFC). The effect of this process has been investigated by NASA and presented to the scientific community. JACIE team investigations also discovered that Space Imaging incorrectly applied the MTFC algorithm, or kernel, creating overcompensation in the image cross-track direction and an undercompensation in the along-track direction. Space Imaging subsequently rotated the MTFC kernel to correct the error. Space Imaging validation findings were reviewed and shared with the scientific community during the High Spatial Resolution Commercial Imagery workshops held in March 2001, March 2002, and May 2003. With this workshop, JACIE fulfilled a recommendation from the National Research Council report (2002) of "facilitating direct communication between members of the scientific community and the private sector."NIMA also was instrumental in revealing an error in the block adjustment of IKONOS images. This error was investigated by Space Imaging and subsequently corrected. Additionally, USGS evaluated digital elevation models (DEMs) produced from IKONOS stereo pairs and found that in some cases, the vertical accuracy of the DEMs was worse than what was expected (i.e., the accuracy exceeded the expected error limit). As a result, Space Imaging modified its DEM production procedures. This positive interface between the JACIE team and Space Imaging lead to production of a higher quality product by Space Imaging.

Several commercial companies have proposed to emulate the NASA characterization process. This could result in having systems characterized according to NASA's preferences; however, independent assessments may become difficult because of the extremely small validation community. Only a small number of experts exist in this area, and many of these experts use very similar validation methods. NASA should begin research and development of alternative validation approaches to ensure continued independent characterization.

5.4 Centralized Management Organization

The existence of a centralized organization for the administration and management of the SDP greatly facilitated the effectiveness of the program. The SDP functions much like a typical NASA mission in that it has tasking, verification and validation, data distribution, and data archiving components. In addition, the SDP also must manage the complexities of commercial IDIQ contracting, continual product deliveries, and vendor invoicing/payment. All of these functions were performed and/or coordinated at Stennis Space Center (SSC).

Several benefits resulted from the centralization of these functions. First, because SSC performed contract management and coordinated science tasking, SSC served as the interface to both the science community and the SDP companies. Thus, ESE scientists did not have to implement individual data purchase contracts or handle contracting issues. Likewise, the SDP companies did not have to interact with hundreds of science investigators. In most cases, SSC served as the interface between science invesigators and data vendors to resolve issues concerning tasking and questions about SDP data. Some direct company-scientist interactions occurred when it was more efficient to do so. One opinion expressed by the National Research Council (2002) was that direct company-scientist interactions were more effective with a government agency acting as mediator. Centralized data receiving, delivery verification, and data archiving greatly facilitated NASA's independent data characterization effort. The SSC characterization team had access to all SDP data for evaluation purposes, which gave the team the ability evaluate problems. In many cases, scientists were able to consult with SSC personnel, who understood the impact of data quality issues on science research.

The centralized functions, science and industry interactions, and independent characterization efforts allowed SSC to gain significant insight, rather than oversight, into the commercial sector and to share this insight appropriately with the science community. This process has increased confidence in the commercial sector's ability to meet science needs.

5.5 Export Control, Data Licensing, Data Archival, and Tasking Prioritization

Understanding issues regarding export control, data rights, and long term archival is crucial to successful commercial data purchases. The types of data distributed through the SDP require up-front commodity classification to determine International Traffic in Arms Regulations (ITAR) applicability. ITAR issues associated with Intermap's STAR-3*i* data initially caused delays in data delivery to scientists. Export control issues should be addressed early in any future data purchase efforts.

The SDP contract provision for data licensing allowed data distribution within the NASA ESE affiliated science community but did not permit free and open distribution for the general public. Free and open data distribution policies are not typically well received by commercial industry. This issue was heavily debated early in the SDP program and is listed as a concern in the National Research Council report (2002). There was great concern that the majority of the data purchased through the SDP would not ever become part of the nation's global archive-a valuable resource for gaining knowledge about the Earth and how it is changing. Additionally, some scientists have requested access to raw data and intermediate products, which most vendors are reluctant to supply because of competitive concerns. In the future, special contract negotiations and pricing arrangements will likely be required to provide appropriate data licensing that better address science needs. The significance of long term data archiving and distribution was somewhat underestimated in the SDP. At the conclusion of the SDP, approximately 25 TB of data will exist in the SDP archive, and approximately 31.3 TB have been distributed to science users. Much of this archived data is still desired by NASA researchers. Thus, data archiving and distribution functions are still on-going, even though the SDP program has, in essence, come to an end. Additionally, because of data licensing provisions, access to the majority of the SDP data must be limited to only NASA-affiliated researchers (the exception is EarthSat, whose data products can be distributed freely to the general public). This creates an additional step in the distribution process to verify that those requesting data are affiliated with NASA's ESE. It future data purchases, funding for long term archiving and distribution must be allocated to maximize the long term utility and value of the data. Future licensing of data should also incorporate "sunset clauses" to allow data to revert to pubic archive after a certain amount of time has passed. The National Research Council (2002) also discussed the need for long-term archival of data purchased through the SDP for use in change detection studies.Tasking prioritization under the SDP contracts lacked definition. In many instances, the government's tasking requests were in competition with the requests of the vendor's many other commercial customers. As a result, verification and validation acquisitions, and other special collections requiring a very small acquisition window, were not easily obtained. The National Research Council (2002) noted that SDP tasks were often given lower priority than were the vendors' other commercial tasks. In addition, tasking status information was often not made available to customers. In the future, customers may be required to negotiate tasking priorities and associated pricing prior to submitting tasking requests.

6.0 Summary and Challenges

Through the Scientific Data Purchase program, NASA has provided affiliated ESE research scientists with high-quality remote sensing data with which they have enhanced and advanced their Earth science studies. The data has proven to be invaluable to many of the recipients and have had significant impact on many projects as evidenced through publications and presentations. NASA provided this data to its Earth scientists at a reduced risk and cost to the government, when compared to traditional government-build approaches. Through evaluation of the SDP process, several critical lessons were learned: 1) SDP data has proven itself very useful to NASA scientists, 2) the commercial remote sensing industry is maturing, 3) independent characterization as well as verification and validation is critically important, and strategic partnerships can facilitate, 4) a centralized organization for management and for verification and validation are very beneficial, and 5) issues such as licensing and data archival are critical to the success of a data purchase effort.

Following the initiation of the SDP, the Commercial Space Act of 1998 (U.S. House, 1998), Public Law 105-303, was enacted to encourage the development of the United States' commercial space industry. Part of this legislation required that *"NASA, and where appropriate, other Federal agencies and scientific researchers, acquire, where cost-effective, space-based and airborne Earth remote sensing data, services, distribution, and applications from a commercial provider"*(U.S. house, 1998). Thus, if the commercial sector can provide data that is deemed worthwhile to the NASA science community, NASA must purchase this data commercially. In addition, the U. S. Commercial Remote Sensing Policy released in April 2003, has directed the U.S. government to consider using spaceborne commercial remote sensing capabilities, to the maximum reasonable extent, to satisfy their imagery and geospatial needs (OSTP, 2003). However, several challenges face NASA and other government agencies interested in implementing remote sensing data purchase programs.

For instance, NASA and other government agencies must define a method to make commercial data and data products regularly available. The Scientific Data Purchase program was the result of a Congressional directive to NASA to procure $50 million of remote sensing data (U.S. Senate, 1996). This directive was followed by a similar Congressionally mandated $20 million data purchase effort in 2001(U.S. House, 2000). Once the 2001 data purchase is complete, there will be no existing NASA contracts to purchase commercial remote sensing products. Scientists interested in using commercial data in their research will be required to purchase products on their own, through direct interaction with a vendor.

A related issue is the identification and selection of the types of data that should be purchased. In the SDP, a wide net was cast across the entire private sector, allowing companies to propose products they perceived as potentially valuable to Earth science research. This approach allowed a NASA science panel to evaluate and select those products having the greatest potential benefit to Earth science. Evaluation of the available commercial data products against a set of NASA Earth science and applications needs is essential. In addition, systematic studies of data requirements for various research and applications would be extremely beneficial in comparing research needs with commercial data specifications.

Another major challenge is identifying the funding required to purchase commercial data on an on-going basis. The SDP has provided data at no cost to NASA project scientists. The availability of remotely sensed data augmented many projects; some projects require additional data to complete the research, but funding is not available. Were it not for the SDP, the prohibitive cost of the imagery might have prevented certain projects from developing, as few researchers have the funding necessary to purchase required datasets. The National Research Council (2002) also noted that many scientists do not have the resources necessary to purchase commercial data. The lack of successive funding for new data acquisitions has interrupted the progress of many projects. If it is determined, based on this report and/or other information, that commercial data has value to the NASA science community, then associated funding requirements and a means to budget for future data procurements should be addressed. Currently, NASA's approach to addressing this issue, is to permit scientists responding to NASA Research Announcemnts (NRAs) to propose use of commercial remotely sensed data as part of their NASA research proposal, and to include the costs of such data in their corresponding cost proposals.

Data policy and licensing issues are a significant challenge that must also be addressed. In a majority of NASA data purchase contracts, licensing provisions permitted free distribution within the NASA affiliated researchcommunity. This restriction is in contrast to the free and open distribution policy of most government operated systems, thus creating limitations on research utility for some researchers. Free and open distribution, while potentially providing increased marketing for the private sector, may also impact data resale value. The National Research Council (2002) suggested that the government should not only negotiate for open distribution rights, but also for the data providers to reduce the cost of older datasets for science researchers. Sharing of data between government agencies must also be considered.

7.0 Conclusions and Recommendations

The SDP has successfully demonstrated a new way of doing business and has achieved the original program goals of obtaining Earth science data from the private sector, and demonstrating that industry is willing to accept the majority of up-front financial responsibility when providing data to the government. However, as is pointed out in the National Research Council's 2002 report, data purchase programs are still maturing. By evaluating this program, assessing the strengths and weaknesses, applying the lessons learned, and addressing remaining challenges, NASA and its commercial partners can expand the resources available to the ESE community in its quest for knowledge about the Earth and its changing environment.

This evaluation was conducted by NASA's Earth Science Applications Directorate at Stennis Space Center, the organization responsible for implementation and administration of the Scientific Data Purchase. Although this assessment attempted to evaluate the SDP in an objective manner, a more thorough and independent review is needed. It is recommended that an independent review team conduct an additional review of the SDP. The National Research Council (2002) also recommends a thorough, independent review of the SDP. This review should include 1) a thorough assessment of the scientific impact of the SDP by a qualified science team, 2) an industry analysis to understand the benefits and issues experienced by the SDP vendors, and 3) an assessment of the SDP management processes including contracting, administration, tasking, verification and validation, distribution, and archiving.

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Data Provider	Image Data Product	Sensor	Data Type	Pixel Size	Horizontal Positional Accuracy	Quantization	Radiometric Accuracy	Maximum Acceptable Cloud %
EarthSat	Orthorectified MSS	Landsat MSS	MSS	57 m	±100 m	8 bits	NA	< 20%
	Orthorectified TM	Landsat TM	TM	28.5 m	±50 m	8 bits	NA	< 20%
	Orthorectified TM Mosaics	Landsat TM	TM	28.5 m	±50 m	8 bits	NA	< 20%
EarthWatch	Orthorectified Image Maps	STAR-3*i* IFSAR	X-Band SAR	2.5 m	±2.5 m	8 bits	NA	N/A
	Digital Elevation Models	STAR-3*i* IFSAR	X-Band SAR	10 m	±2.5 m	8 bits	NA	N/A
Positive Systems	IM-R1I-55 – Corrected Orthorectified Imagery	ADAR 5500	MS	0.7 m	±100 m (center pt)	8 bits	± 10% Abs ± 5% Rel	< 10%
	MOS-G1 – Geo-Mosaic	ADAR 5500	MS	0.7 m	± 12.2 m (benign) to ±50 m (extreme relief)	8 bits	NA	< 10%
Space Imaging	Original Pan	IKONOS	Pan	1 m	± 250 m (std) ± 3 m (precision)	11 bits	± 10% Abs ± 5% Rel	< 10%
	Original MS	IKONOS	MS	4 m	± 250 m (std) ±5 m (precision)	11 bits	± 10% Abs ± 5% Rel	< 10%
	Master (Orthorectified) Pan	IKONOS	Pan	1 m	±12.2 m (std) ±2 m (precision)	11 bits	± 10% Abs ± 5% Rel	< 10%
	Master (Orthorectified) MS	IKONOS	MS	4 m	±12.2 m (std) ±5 m (precision)	11 bits	± 10% Abs ± 5% Rel	< 10%
	Stereo Pair	IKONOS	Pan	1 m	±25.4 m	11 bits	NA	NA
	Stereo Pair	IKONOS	MS	4 m	±25.4 m	11 bits	NA	NA
	Model DEM, Level D	IKONOS	NA	15 m	±25.4 m	NA	NA	NA

Table 1. Overview of NASA Scientific Data Purchase products. MS – Multispectral
Pan – Panchromatic

RFO-13-SSC-O-97-21
ATTACHMENT 2: Technical Requirements

MTPE Scientific Data Buy Program

Phase I

Appendix B. Customer Feedback Letter

Customer Feedback Letter

RETURN TO: Troy Frisbie
Scientific Data Purchase Project Manager
Earth Science Applications Directorate
National Aeronautics and Space Administration
Stennis Space Center, MS 39529

TO: NASA Earth Science Enterprise Scientific Data Purchase data recipients

NASA's Earth Science Applications Directorate at Stennis Space Center, Mississippi, is dedicated to enhancing and improving current and future Earth Science Enterprise Scientific Data Purchase (SDP) activity. In an effort to assure the Data Purchase project is meeting the needs and expectations of the data recipients in the scientific community, we would appreciate your taking the time to answer the following questions:

Data Recipient's Name ____________________________ Date ___________________

Data Recipient's Organization/Affiliation______________________________________

SDP Task No. ___________________ or Order No.________________

Date Data Shipped ____________________

Type of Data: ☐ Positive Systems ☐ EarthWatch ☐ EarthSat ☐ Space Imaging

QUALITY ASSESSMENT

1. Please rate from 1 (data seriously flawed) to 10 (data exceptional) your impression of the quality of the data received.

Rating __________

Comment:

2. Please rate from 1 (service non-responsive) to 10 (service exceptional) your experience with the Scientific Data Purchase process from data request through data delivery.

Rating __________

Comment:

3. Please rate from 1 (service non-responsive) to 10 (service exceptional) your experience with the Scientific Data Purchase data vendors (Earth Watch, Space Imaging, Positive Systems, EarthSat) as applicable.

Rating __________

Comment:

PROGRAM ASSESSMENT

4. Please rate from 1 (data not useful) to 10 (data highly useful) your impression of the usefulness of the data in your research/application.

Rating __________

Comment:

5. Please rate from 1 (adverse effect) to 10 (no effect) any limitations that the Data Rights agreement had on the utility of the data or on your ability to accomplish research objectives.

Rating __________

Comment:

6. Please let us know if there have been any publications as a result of research using the data.

Publications:

7. For us to better report to our sponsors, please describe any benefits to the U.S. taxpayers derived from your use of the data.

8. Do you encourage continuation of the current Scientific Data Purchase effort into the future?

9. Do you encourage the Scientific Data Purchase project to pursue new sources of commercial data, and if so, what data products?

10. Please provide any other general thoughts or suggestions as to how we can improve the project.

Thank you for taking the time to complete this questionnaire. Feel free to contact me anytime at 228-688-1989 if you have any questions or comments regarding the NASA ESE Scientific Data Purchase project.

Sincerely,

Troy Frisbie
Scientific Data Purchase Project Manager
Earth Science Applications Directorate
National Aeronautics and Space Administration
Stennis Space Center, MS 39529

Appendix C. E-mail Survey

Email disseminated to all SDP users who received data:

Dear Scientific Data Purchase Participant:

Dr. Lauren Underwood is compiling a summary of the impact of the commercial data distributed by NASA through the Scientific Data Purchase (SDP) project. This summary will be forwarded to NASA Headquarters, and used to evaluate the utility of commercial data in the science and applications projects sponsored by the Earth Science Enterprise. As a recipient of data from SDP, it would be of great assistance to NASA, and a potential benefit to the remote sensing community, if you would take a few moments and supply the information requested below.

Our records show that you received the following data set(s) from the SDP:
(**script insert*--* order#/task#, data type, location, data product, total # of scenes, date data was sent)

For each data set, please supply:

- A brief summary of the impact the SDP had on your research (e.g. comments regarding SDP data's effectiveness, the role SDP data had in enhancing your research, the role SDP data may play in future research/application projects)
- A list of publications (including abstracts, presentations, and pending work) that have incorporated the use of SDP data (if possible, please send reprint copies as well); and/or a list of data products or applications derived from SDP data
- Please indicate any issues (technical, administrative, other) that precluded effective use of the data you received
- Please express your interest in attending/presenting your SDP data results at a future workshop focusing on the results of the SDP

Your response to this message is requested by March 11, 2002, and August 2, 2002, respectively. Please forward any and all correspondences/questions to Lauren W. Underwood, Ph.D., LMSO, Building 1105 Stennis Space Center, MS 39529, Ph: 228-688-2096, Email: Lauren.Underwood@ssc.nasa.gov.

Thank you for taking the time to provide us with this important information.

Sincerely,

(Signature on file)

Troy E. Frisbie
Scientific Data Purchase Project Manager
NASA Earth Science Applications Directorate
Stennis Space Center, MS
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Lauren: Aren't #204 and #205 the same article?

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REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
23-09-2003		

4. TITLE AND SUBTITLE The NASA Scientific Data Purchase: Summary and Evaluation	**5a. CONTRACT NUMBER** NAS13-650
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Earth Science Application Directorate LMSO-Stennis Program Remote Sensing Directorate	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) LMSO-Stennis Program	**8. PERFORMING ORGANIZATION REPORT NUMBER** SE-2003-09-00087-SSC
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Earth Science Directorate	**10. SPONSORING/MONITOR'S ACRONYM(S)**
	11. SPONSORING/MONITORING REPORT NUMBER

12. DISTRIBUTION/AVAILABILITY STATEMENT
Publicly Available STI per form 1676

13. SUPPLEMENTARY NOTES
Journal Name and URL- Full report http://www.esa.ss.nasa.gov
Condensed report: Photogrammetric Engineeering and Remote Sensing

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19b. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Earth Science Directorate
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	106	